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How Specific is Domain-Specific Slowing? Evidence for a General Form of a Domain-Specific Mechanism

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How Specific is Domain-Specific Slowing? Evidence for a General Form of a Domain-Specific Mechanism

by

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Table of Contents

List of Figures

List of Tables

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Cynthia C. Flores

Washington University in St. Louis

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Dedicated to my parents who crossed a border so I could be here.

ABSTRACT OF THE DISSERTATION

How Specific is Domain-Specific Slowing?

Evidence for a General Form of a Domain-Specific Mechanism

by

Cynthia C. Flores

Doctor of Philosophy in Psychological and Brain Sciences

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Faces are special not just because our ability to quickly and accurately process faces is integral for social functioning throughout our lives, but also because faces are considered a unique class of visual stimuli (i.e., faces rely more on holistic processing than objects and there exist specialized, face-specific regions in the brain). Behavioral and neuropsychological research point to face processing as dissociable from other kinds of visuospatial processing. Although there is evidence that neural specificity for faces is retained in older adults, there is also evidence that age-related impairments are greater in face processing, relative to object processing. Using a large set of matched perceptual tasks in the face and object domain, I tested the hypothesis that age-related cognitive slowing proceeds at a different rate for face processing compared to slowing associated with object processing. Analyses clearly revealed only one slowing function

which indicated that older adults' performance could be predicted by young adults' performance, irrespective of domain (i.e., whether the tasks involved face processing or object processing). Bayes Factors analyses also showed strong support for the null hypothesis of equivalent age-related slowing of both face and object processing. Taken together, the findings show that the rates of age-related slowing in the face and object domains are indistinguishable and support the view that a single mechanism governs speed of processing within the visuospatial domain, regardless of the type of stimuli.

Chapter 1: Introduction

In the past few decades, older adults have become more concerned about cognitive decline than they dread bodily dysfunction or disease (MetLife, 2006), and research within the field of aging has endeavored to explain and map the course of age-related changes in cognitive processing. Although decrements in memory ability often take the cognitive spotlight, age-related slowing has been called the most reliable and pervasive phenomenon in cognitive aging (Kail & Salthouse, 1994; Myerson, Hale, Wagstaff, Poon, & Smith, 1990; Salthouse, 1985). Indeed, a reduction in processing speed is the most salient difference between older and younger adult performance on almost any task (for reviews, see Cerella & Hale, 1994; Salthouse, 1985; Verhaeghen, 2014).

Processing speed simply refers to the time it takes the brain to process information; it typically is measured as a person's response time (RT) to a visual or auditory stimulus on a cognitive task that requires a decision (Jensen, 2006; Verhaeghen, 2014). Researchers have proposed that speed is a basic aspect of cognition, a heritable trait, and some have argued that it is significantly correlated with measures of intelligence (Jensen, 2006; Shepperd & Vernon, 2008; Stankov & Roberts, 1997). Deary and Der (2005) even proposed that a person's age at death is correlated with cognitive speed.

The decrease in cognitive speed associated with aging, however, does not proceed at a uniform rate in all domains. In other words, the kind of information being processed (e.g., lexical vs. visuospatial) matters when it comes to age-related slowing (Lawrence, Myerson, & Hale, 1998; Lima, Hale, & Myerson, 1991). There exist domain-specific mechanisms that can account for the differential rates of slowing observed in separate domains, rather than a general mechanism responsible for slowing across all domains (Cerella, 1985; Cerella, Poon, & Williams, 1980; Lima et al., 1991). It is unclear, however, how many dissociations exist; processing different classes of information within a domain could be associated with different rates of slowing. For instance, not all visuospatial information is processed in the same way. It has been suggested by many researchers that face stimuli are 'special,' and behavioral and neuropsychological evidence point to face processing as a dissociable ability from other kinds of visuospatial processing (Rhodes, Byatt, Michie, & Puce, 2004; Tong, Nakayama, Moscovitch, Weinrib, & Kanwisher, 2000). For this reason, face processing may not show the same rate of slowing as processing other, non-face visual information.

Undoubtedly, human faces are one of the most important social stimuli, and fast and reliable processing of faces is a key factor for social functioning throughout our lives. Failure to recognize friends, family, or acquaintances can be socially embarrassing and occurs in young adults, adults with face impairments, and the elderly, leading to frustration in social situations (De Renzi, Faglioni, Grossi, & Nichelli, 1991; Kanwisher & Yovel, 2006; Schweick et al., 1992). Compared to younger adults, older adults show deficits in nonverbal encoding of face stimuli (Backman, 1991; Ferris et al., 1980), forming face-name associations (Naveh-Benjamin, Guez, Kilb, & Reedy, 2004), and perceiving some emotional information from faces (Stanley & Blanchard-Fields, 2008; Suzuki, Hoshino, Shigemasu, & Kawamura, 2007). Some research suggests that recognition memory in older adults is poorer with unfamiliar faces when they cannot rely on prior knowledge (Backman, 1991). Thus, older adults may have more difficulty recognizing new or unfamiliar individuals in their daily interactions. Reports of age-related decrements on face processing tasks are especially troubling when considering the social difficulties that may impact older adults and the implications of using testimony from older eyewitnesses for suspect identification (Memon, Bartlett, Rose, & Gray, 2003; Memon, Hope, Bartlett, & Bull, 2002; Searcy, Bartlett, & Memon, 1999). For these reasons, investigating the nature of age-related changes in face processing is important.

Compared to face processing, however, older adults do not show the same level of impairment when processing objects, which suggests that aging may disproportionately affect some mechanisms that are specific to processing faces; aging affects face and object processing abilities differently (Boutet & Faubert, 2006). In addition to examining overall differences between older and younger adults' performance on speeded tasks, understanding the mechanisms behind age-related slowing in face processing relative to other visual information is essential to defining functional differences in processing within the visuospatial domain. Reports of age-related changes in visual processing abilities suggest that impairments are greater in face recognition tasks relative to object recognition tasks (Boutet & Faubert, 2006), which makes the examination of differences between face processing and the processing of other visual stimuli an intriguing area of research from the perspective of age-related slowing.

In the present dissertation, face and object processing refers to the abilities associated with perceiving and making judgments about stimuli, including perception and processing of features, symmetry, and identity—but not delayed recognition or memory. This is an important distinction from all-encompassing definitions of processing which include performance measures from delayed-response tasks. Numerous studies purporting to study processing have also included tasks containing a working memory component, which makes it difficult to determine whether recorded RTs measure processing speed or additional processes related to working memory and recognition.

To date, few studies have taken a systematic approach to investigate the rate of slowing for face processing in direct comparison to other non-face visual stimuli, which would establish a foundation from which to draw conclusions about the mechanisms underlying slowing within the visuospatial domain. Additionally, no studies have compared face and object processing speed extensively, using closely matched face and object tasks and collecting more than a few performance indicators from the same group of individuals. The current study aimed to determine whether there is an age-related dissociation in processing speed between face processing, which is considered a unique class of visual stimuli, and object processing, which also falls under the visuospatial domain.

Chapter 2: Literature Review

This chapter provides a brief review of the literature concerning face-specificity, age-related deficits in face processing, theories of processing speed, and previous findings of dissociations in the rate of slowing, all of which lay the groundwork for the current study.

2.1 Face Specificity

There is strong support for a specialized neural system for face processing that is functionally and anatomically distinct from an object-processing system (Daniel & Bentin, 2012; McCarthy, Puce, Gore, & Allison, 1997; Rhodes, Byatt, Michie, & Puce, 2004), and it is possible that differential rates of slowing may arise from these two distinct systems (i.e., face and object processing. Experimental research has shown that faces, unlike non-face visual stimuli, are processed more holistically, relying on configural more than on featural information, which supports the view that faces and objects are processed in qualitatively different ways (Bartlett, Searcy, & Abdi, 2003; Freire, Lee, & Symons, 2000; Maurer, Le Grand, & Mondloch, 2002; McKone, Martini, & Nakayama, 2001). Additionally, evidence from imaging studies, electrophysiological studies, and cases of selective brain lesions offer support for the neural specificity of face processing (Parvizi et al., 2012; Moscovitch, Winocur, & Behrmann, 1997; Rossion & Jacques, 2008; Wada & Yamamoto, 2001; Yovel & Kanwisher, 2004).

A classic method of assessing holistic processing of faces and objects involves comparing performance on conditions using upright visual stimuli to conditions using upside-down stimuli (Bartlett et al., 2003; Freire et al., 2000; Goffaux & Rossion, 2007; Maurer et al., 2002; Yin, 1969). The current consensus is that inversion disrupts holistic processing, but featural information is less vulnerable than configural information (Bartlett et al., 2003; Freire et al., 2000; Maurer et al., 2002). Performance on recognition and discrimination tasks is disproportionately better for upright faces than for inverted faces but objects are not affected by inversion to the same extent (Bartlett et al., 2003; Freire et al., 2000; Maurer et al., 2002). The face inversion effect is thought to occur because configural information is central to processing faces holistically but objects rely more on part-based processing of features (Freire et al., 2000). To test the theory that configural information is more important in face processing, researchers examined whether the face inversion effect was present for faces that differed either in the spacing between features (configural information) or in featural information. They found that discrimination accuracy was significantly worse for inverted faces in the configural condition but there was no difference in performance between upright and inverted faces in the feature condition (Freire et al., 2000; Goffaux & Rossion, 2007).

Further behavioral evidence of differences between face and object processing comes from the part-whole task, another common way to assess holistic processing (Bartlett et al., 2003). In part-based (i.e., feature-based) processing, when parts of an object are explicitly represented in the visual system, these parts should be easy to identify in isolation. During holistic processing, however, it is difficult to decompose the whole into its parts and accurate identification of a feature is facilitated when it is presented in the context of the whole. Tanaka and Farah's (1993) part-whole study found that parts of faces were more easily identified when they were presented in the context of the whole face than when they were presented in isolation; houses, inverted faces, and scrambled faces did not show this effect. Findings from numerous studies investigating holistic processing with the part whole task consistently support the view that upright faces are a unique class of visual stimuli and, more than other types of stimuli, engage holistic processing mechanisms (Boutet & Faubert, 2006; Daniel & Bentin; Tanaka & Farah, 1993).

Additionally, imaging studies have identified specialized regions in the brain that show greater activation to human faces relative to non-face objects, including other body parts and facial features presented alone (Calder & Young, 2005; Kanwisher, McDermott, & Chun, 1997; Tong et al., 2000). Specifically, the fusiform face area (FFA) is considered one of the core regions of face processing, responding maximally in tasks that require attention to identity and processing of features (Calder & Young, 2005; Haxby, Hoffman, & Gobbini, 2000). Research comparing FFA activation during face and object processing has shown that the FFA is activated specifically in response to face stimuli, and activation is not associated with specific tasks that tap into configural processing; the FFA is activated even when the task requires part-based processing of faces but is not activated in object-processing tasks even when configural information is relevant to the task (Yovel & Kanwisher, 2004). In one experiment, participants identified objects and faces at a basic level (e.g., is this a bird or a face?) or at the subordinate level (e.g., is this a pigeon or Harrison Ford?). Activity in the FFA was correlated with successfully detecting the presence of a face and identifying a face. Importantly, successful detection or identification of a particular exemplar from a homogenous class of objects was correlated with activation of other regions in the ventral occipitotemporal cortex, but not with activity in the FFA, which suggests that the FFA is not activated simply when discriminating between similar objects (Grill-Spector, Knouf, & Kanwisher, 2004).

In addition to findings from imaging studies, face-specific event-related potentials have been implicated in face detection and provide further evidence of a dissociation between face and object processing (Allison, Puce, Spencer, & McCarthy, 1999; Bentin, Allison, Puce, Perez, &

McCarthy, 1996; Rossion & Jacques, 2008; Yovel, 2016). The N170 component is an electrophysiological response that peaks 170 ms after stimulus onset and is larger for faces than other non-face visual stimuli (Bentin et al., 1996; Rossion & Jacques, 2008; Yovel, 2016). The N170 shows a face inversion effect (Rossion & Gauthier, 2002), is present from infancy (de Haan, Pascalis, & Johnson, 2002), and cannot be explained by the high perceptual similarity that exists between face stimuli (Rossion & Jacques, 2008), which is consistent with neural-specificity for faces.

Perhaps the most compelling evidence supporting face-specificity comes from studies of patients with deficits restricted exclusively to face or object processing or, in one case, evidence that electrical brain stimulation of face-specific regions disrupts processing of faces, but not objects. In extremely rare cases, selective brain damage impacts face-processing centers and results in acquired prosopagnosia, an inability to recognize and distinguish faces (De Renzi et al., 1991; Kanwisher & Yovel, 2006). For instance, after suffering a brain hemorrhage, a Japanese man lost the ability to recognize familiar faces including friends, family, famous faces, and even his own face (Wada & Yamamoto, 2001). The injury impaired his ability to recognize faces, but his visuospatial perception and processing of non-face objects remained intact. Further examination of the man's injury uncovered a small lesion in the right fusiform and lateral occipital region, which has been identified as the primary center for face processing (Kanwisher, 2000; Kanwisher & Yovel, 2006; Wada & Yamamoto, 2001). In a famous case of object agnosia, C.K. was unable to recognize objects after suffering brain damage in a motor-vehicle accident (Moscovitch et al., 1997). Patient C.K. suffered from associative visual object agnosia which means he could not assign meaning to a visual non-face stimulus. His face processing abilities were unaffected, however, and, on tests measuring face perception and recognition abilities, he performed as well as 12 controls (Moscovitch et al., 1997). C.K. was able to copy pictures and draw items from memory and could also identify the component parts of objects but failed to integrate them into a cohesive whole with meaning (Moscovitch et al., 1997). He was often able to identify objects by reasoning about their parts, though not without frequent mistakes; through reasoning, he misidentified a pen standing upright in a holder as a trophy and didn't realize it was a pen until he touched it (Moscovitch et al., 1997). In another study, a patient suffering from medication-resistant seizures had intracranial electrodes implanted to pinpoint the source of the seizures (Parvizi et al., 2012). When electrodes that were implanted over face-specific regions were electrically stimulated, the patient was unable to recognize famous individuals presented to him, which he had previously correctly identified, but his ability to accurately name famous places was not disrupted. The patient also reported that the face of the examiner in the room "metamorphozed" and became suddenly distorted when an electrical charge was delivered to face-specific regions (Parvizi et al., 2012). These cases provide substantial evidence of a double-dissociation between face and object processing.

Importantly, qualitative differences between face and object processing are apparent across the lifespan. Like young adults, older adults rely more on featural information to process objects and on configural information to process faces, and the ability to encode second-order relations of facial features and structural properties is retained in older adults (Boutet & Faubert, 2006; Daniel & Bentin, 2012; Hildebrandt, Wilhelm, Herzmann, & Sommer, 2013; Hildebrandt, Wilhelm, Schmiedek, Herzmann, & Sommer 2011). Boutet & Faubert (2006) found that older adults show a typical face inversion effect and perform similarly to young adults on a part-whole task, which signifies intact processing of configural information for faces. Additionally, neural research has found that, although there are some age-related neural changes, young adults and older adults show a robust N170 component in response to faces but not objects, which is evidence that aging does not lead to dedifferentiation and faces and objects continue to elicit different neural responses (Daniel & Bentin, 2012; Gao et al., 2009). Thus, the ability to process faces holistically is preserved in older adults and there is no evidence of a loss of neural specialization for faces (Boutet & Faubert, 2006; Daniel & Bentin, 2012).

Although there is a wealth of evidence demonstrating that there are processing differences between faces and objects, it is not clear whether these differences also constitute separate mechanisms responsible for age-related slowing in tasks involving objects and tasks involving faces. Given the magnitude of the experimental, imaging, and neuropsychological evidence of the dissociation between object and face processing, it is plausible that these two domains may show different rates of slowing. On the other hand, very few studies have systematically explored dissociations in speed comparing faces and objects using a large number of tasks, and there are few studies that have investigated slowing in perceptual tasks (i.e., tasks that do not rely on recognition memory), which does not rule out the possibility that there is no dissociation in face and object processing.

2.2 Age-Related Decrements in the Face Domain

It is well-documented that, compared to young adults, older adults show large decrements on face processing tasks, raising concerns about the impact of face-related deficits on social functioning in older age and questions about the reliability of eyewitness testimony from older adults (Bartlett & Fulton, 1991; Boutet & Faubert, 2006; Boutet, Strater, & Fulton, 1991; Crook & Larrabee, 1992; Memon et al., 2002). Especially on tests of face recognition, older adults tend to perform more poorly, showing a higher rate of false alarms to new faces (Boutet & Faubert, 2006; Grady et al., 1995; Nyberg et al., 2003; Searcy et al., 1999). It is not well-known, however, whether the mechanisms responsible for age-related decrements in face processing also result in a differential rate of slowing for faces compared to other kinds of visual stimuli. In the following section, I outline some findings of age-related declines in face recognition and processing.

In studies examining face recognition in the context of eyewitness scenarios, researchers have found that older adults have larger false alarm rates than younger adults in a variety of eyewitness recognition and lineup tasks; (Crook & Larrabee, 1992; Memon et al., 2002; Searcy et al., 1999). Additionally, older adults become increasingly more impaired on face recognition tasks with advancing age, especially when they must choose between new faces and previously presented foils, which suggests that source memory issues come into play (Memon et al., 2002). There is also existing evidence that older adults are more impaired on face than object recognition tasks relative to their young adult counterparts. For example, Boutet and Faubert (2006) compared face recognition to recognition of chairs and houses in older and younger adults and found that, unlike younger adults, older adults were less accurate on face recognition tasks than object recognition tasks, which supports the view that age-related deficits in visuospatial processing impact faces more than objects.

Although face-related deficits on perceptual tasks are typically less pronounced than measures of accuracy on recognition tasks, there are numerous reports of decreased accuracy in face perception in older adults relative to younger adults (Grady, McIntosh, Horwitz, & Rapoport, 2000; Grady et al., 1995; Hildebrandt, Sommer, Herzmann, & Wilhelm, 2010). For example, Grady and colleagues (2000), examined face perception using degraded and non-degraded face-matching tasks and found that although older adults were not more impaired by increasing degradation of face stimuli, overall, they were less accurate than younger adults.

Another study assessed age-related changes in face cognition abilities (i.e., face memory, face perception, and the speed of face cognition) in younger and older adults and found that the speed of face cognition showed the largest decrease in performance out of all tasks; decreases in the ability to process and recognize faces quickly were apparent as early as age 30 (Hildebrandt et al., 2010). According to Hildebrandt and colleagues (2010), decrements in face memory (i.e., the abilities associated with storing and retrieving face information) are evident beginning at age 40 but declines in face perception (i.e., the ability to perceive face features and configural information) are not apparent until after age 60. Considering that in many studies the older participant group consists of 'younger' older adults, including participants under the age of 60, the finding that declines in face memory occur earlier than in perception could explain why reports of face recognition deficits are more prevalent in the literature.

According to some research, age-related deficits in face cognition abilities may be due to neural differences that occur during encoding (Daniel & Bentin, 2012; Grady et al., 1995). Differences between older and younger adults in the pattern of cerebral blood flow during the encoding of faces have been observed, which are associated with reduced accuracy in recognition memory in older adults (Grady et al., 1995). Other age-related neural changes in face processing are also apparent (e.g., a delayed onset of the face-specific N170) and may explain some of the observed face-specific impairments (Daniel & Bentin, 2012; Gao et al., 2009; Grady et al., 1995). Decrements in face processing, however, are unlikely to be caused by dedifferentiation between face processing and object processing. Like younger adults, older adults also show a robust face inversion effect, an advantage for whole faces over parts on a part-whole task, and research examining memory and perception of faces and objects is consistent with the view that specificity for faces is preserved in older adults (Boutet & Faubert, 2006; Daniel & Bentin, 2012; Hildebrandt et al., 2013; Hildebrandt et al., 2011).

Another plausible explanation for face decrements in older adults arises from correlations of visual acuity and contrast sensitivity with measures of processing speed and memory. This has raised questions over whether visual declines impact cognitive processing of visuospatial stimuli (Anstey, Dain, Andrews, & Drobney, 2002; Anstey & Smith, 1999; Lindenberger & Baltes, 1994; Salthouse, Hancock, Meinz, & Hambrick, 1996). These correlations are more likely to simply be a spurious artifact of age; both visual sensory measures and task performance measures decline with age. Visual acuity is only weakly correlated with face and object processing and it is unlikely that age-related declines in vision are responsible for observed impairments on face processing tasks (Hildebrandt et al., 2013). In a study by Anstey and colleagues (2002), tests of face recognition were associated with age but not with visual acuity or color vision. Stroop tasks, however, were dependent on color vision ability (Anstey et al., 2002). The authors concluded that performance on cognition tasks is only impacted by vision when a specific visual ability is required to form a correct response, such as color processing on the Stroop task. In other visual tasks which do not require a specific visual ability, the relationship between visual ability and visual processing may be uniform, and thus declines in vision are unlikely to explain face-specific deficits. It should be noted, however, that visual abilities could still be correlated with measures of speed and performance on other face processing tasks and visuospatial tasks requiring precise discrimination of features that have not been investigated.

2.3 Processing Speed and Brinley Plots

The study of processing speed first attracted scientific interest in the field of astronomy. A Prussian astronomer, F.W. Bessel, became interested in studying reaction times after learning about a famous incident in 1795 involving a British astronomer, Maskelyne, and his assistant, Kinnebrook (Jensen, 2006). According to the story, Maskelyne fired Kinnebrook due to constant 'errors' when measuring the time required for a star to cross the hairline in a telescope. Since their goal was to establish the standard mean Greenwich time, even an average error of 500 *ms* was deemed impermissible. The task of timing a moving star, which Kinnebrook consistently 'failed,' was similar to coincidence timing tasks in modern psychology which require pressing a button as soon as a moving spot of light is perceived to collide with a line (Jensen, 2006). Years later, Bessel (1820) tested subjects on coincidence timing tasks and discovered reliable differences in reaction time between individuals (Jensen, 2006). Kinnebrook's 'errors' were not errors at all but simply a reflection of individual differences in processing speed.

In addition to individual differences in processing speed, it is consistently slower in older adults than in younger adults on practically any measure, and processing speed is often more strongly correlated with age than accuracy or any other abilities (Cerella & Hale, 1994; Verhaeghen & Salthouse, 1997). When older adults' RTs are longer relative to those of younger adults, it can be difficult to determine whether the older adults are more affected by a manipulation than their young adult counterparts. Researchers must first account for any general age-related slowing (within the domain of tasks under consideration) to determine whether older adults' longer RTs in a particular condition reflect a specific age-related deficit. One method that can be used to answer such questions uses a Brinley plot, in which older adults' group mean RTs are plotted as a function of younger adults' group mean RTs on the same tasks or conditions, which presents a more accurate representation of the general relationship between older and younger adults' performance. For example, when the response times of both age groups can be explained by a single function, older adults' performance must be interpreted as a quantitative effect of increasing complexity and not as a qualitative deficit relative to younger adults. If an exception is observed, specific task conditions might fall reliably above the general slowing function.

In the past few decades, Brinley plots have become a more common method of assessing processing speed differences between older and younger adults; it is a departure from the standard method of looking at absolute differences in mean performance and group-by-condition interactions to examine slowing (Verhaeghen, 2014). The significance of Brinley plots is that a 'true' dissociation can be observed when there is a difference in the underlying relationship between the response times of two groups, and not just an observed age-by-condition interaction.

To illustrate, Brinley (1965) collected 21 pairs of means from the same group of older and younger participants in a task-switching study and observed that the slope of the regression line for switching tasks was essentially the same as the regression line of non-switching tasks. He inferred that the relationship between older and younger adults' response times was the same in both conditions even though task-switching resulted in longer response times and older adults' performance was seemingly affected more than younger adults' performance. That is, because all 21 points fell along the same regression line the plot that would come to bear his name revealed nothing more than increasing task difficulty and thus, older adults' longer response times reflected only a quantitative rather than a qualitative difference between the two age groups.

2.4 An Explanation of Processing Speed and Slowing

In the dawning days of the cognitive (or Information Processing) revolution, researchers proposed that processing (which behaviorists considered to be located “inside a black box” – i.e., the brain – and therefore not directly observable and unable to broken down into its potentially constituent parts) can be divided into various stages, or components, where each component takes a certain amount of time; in this model, the sum of each component’s duration is the total processing time. By manipulating the processing requirements associated with different stages, cognitive researchers reliably demonstrated that their results depended on the stage of the manipulation. Following the subtraction method, cognitive researchers have successfully conducted research over the past 50 years that have identified numerous task-specific stages (e.g., semantic priming, the Stroop effect, mental rotation of objects, memory scanning).

In the years following the publication of the first Brinley plot, researchers became more interested in age-related slowing, which also gave rise to theories about the observed age-related slowing when performing speeded information processing tasks. When Salthouse turned the spotlight on age-related differences in information processing, he would argue that the main aspects of information processing can be described by three fundamental components: an initial perceptual input stage, a cognitive processing stage (leading to the point at which a decision is made), and a motor output stage (Verhaeghen, 2014).

Within this framework and in the absence of slowing, older adults’ total response time would equal the sum of all processing components of younger adults, RT_older = RT1_younger + RT2_younger + RT3_younger … + RTN_younger. If slowing is caused by impairments or defects at only one stage of processing, older adults’ total response time would equal the sum of all processing components of younger adults except that one of these components would be slowed, RT_older = RT1_younger + k * RT2_younger + RT3_younger … + RTN_younger. The resulting Brinley function would be a line that is parallel to the diagonal, RT_older = RT_younger + a, where 'a' represents the additional processing time needed to complete the task by older adults (for a thorough explanation, see Verhaeghen, 2014).

Alternatively, all stages could experience the same degree of slowing, which Salthouse (1978) called the universal decrement. If older adults' slower RTs can be explained by a single mechanism, then RT_older = a * RT_younger. This would result in a line with a slope greater than 1.0 and an intercept at the origin. Initially, it seemed that a single mechanism sufficed to explain the data. Cerella, Poon, and Williams (1980) also found that age-related slowing was well-described by a multiplicative model that supported general slowing of all processing components.

In the following years, researchers distinguished between tasks that had greater cognitive demands and tasks that tapped into sensorimotor abilities, termed central and peripheral processing, respectively (Cerella, 1985; Cerella, 1990). If it is assumed that similar processing speed tasks also have similar perceptual and motor requirements, the initial input stage and the motor output stage can be combined into one peripheral processing component; RT = central + peripheral. Cerella (1990) found that slowing was greater for tasks that relied more on cognitive processing than for tasks that involved a greater motor component, which implied that central and peripheral processes had different rates of slowing.

In this model of processing, younger adults' response time can be represented by the equation, RT_younger = central + peripheral, and the response time of older adults can be written as RT_older = c*central + p*peripheral. The terms 'c' and 'p' describe the age-related slowing factors in central and peripheral processing, respectively, and the terms 'central' and ‘peripheral’ refer to the central and peripheral processing in younger adults. Because central = RT_younger – peripheral, substituting the central component into the equation to write older adults’ response time as a function of younger adults’ response time yields a Brinley function, RT_older = c* RT_younger + (p-c)* peripheral (see Cerella, 1990 and Verhaeghen, 2014 for a full explanation). The slope of this equation, ‘c,’ is the central slowing factor and ‘(p-c)*peripheral’ is the intercept, which is necessarily negative if ‘c’ is greater than ‘p.’

2.5 Dissociations in Age-Related Slowing

Age-related slowing of cognitive processes is well-documented in the literature (Cerella et al., 1980; Hale, Myerson, Faust, & Fristoe, 1995; Kail & Salthouse, 1994; Myerson et al., 1990; Salthouse, 1978; Verhaeghen, 2014), and originally, it was assumed that one mechanism was responsible for slowing at all stages of processing and across all types of tasks (Salthouse, 1978). However, reports of dissociations in processing speed between peripheral and central processing began to shift perceptions about age-related slowing. Slowing associated with cognitive processing is greater than slowing on sensorimotor tasks (Cerella, 1990).

In addition to the dissociation observed between central and peripheral processing, further studies and meta-analyses have suggested that other task categories may differ in the degree to which processing slows with age. Beginning with Lima, Hale, and Myerson (1991), Hale and Myerson and colleagues have repeatedly found that tasks involving spatial processing have a steeper slowing slope than verbal processing tasks (Hale & Myerson, 1996; Hale et al., 1995; Jenkins, Myerson, Joerding, & Hale, 2000; Lawrence et al., 1998; Myerson & Hale, 1993). A study by Lawrence, Myerson, and Hale (1998) investigated age-related slowing in lexical and visuospatial processing in a series of tasks that measured processing speed. Lexical processing speed was assessed with simple verbal tasks, such as deciding whether two words belonged in the same semantic category (e.g., lion and gorilla) and whether two related words were synonyms or antonyms (e.g., fast and slow). Visuospatial processing tasks consisted of a shape classification task in which participants had to determine whether two shapes were identical regardless of size, an abstract matching task in which participants judged which of two arrays was a better match for a third array based on four dimensions (e.g., color, shape, etc.), and a visual search task which required participants to decide if a red square was present in an array of red circles and green squares. The authors found that both verbal and visuospatial processing time increased with age but slowing associated with visuospatial processing was significantly greater compared to slowing in the verbal domain.

A review of the literature suggests that general slowing is observed within a cognitive domain (e.g., within the verbal or the visuospatial domain) and there may exist domain-specific mechanisms responsible for cognitive speed, which account for differential slowing between domains (Hale & Myerson, 1996; Lima et al., 1991). Although older adults experience cognitive slowing associated with normal aging, there is a clear distinction in the degree of slowing associated with the processing of verbal information and nonverbal (or visuospatial) information, which shows much greater age-related slowing (Hale et al., 1995; Jenkins et al., 2000; Lawrence et al., 1998).

Other dissociations in cognitive speed have also been reported. In a meta-analysis on the negative priming effect, Verhaeghen and De Meersman (1998) compared mean response times in negative priming conditions to mean response times in the baseline condition and found that younger adults had a steeper slope. The authors conclude that although both older and younger adults were susceptible to the negative priming effect, older adults were less susceptible, which is indicative of a dissociation between negative priming conditions and baseline conditions. There is also tentative support for a process-specific model of age-related slowing, which proposes that slowing rates differ between different cognitive processes. For instance, previous research has found evidence of a dissociation between memory scanning tasks and tasks that require simultaneous matching or visual search (Sliwinski & Hall, 1998; Swearer & Kane, 1996). Tasks that have a memory component (e.g., delayed matching or recognition) may show less age-related slowing than non-memory tasks, but this pattern of results could be dependent on the length of the retention interval, and the effect has not been studied extensively.

Dissociations in age-related slowing between peripheral and central processing, between the lexical and visuospatial domain, and between different categories of tasks and cognitive processes have made the view of general slowing untenable; one mechanism cannot account for slowing across all domains (Cerella, 1990; Hale et al., 1995; Swearer & Kane, 1996; Verhaeghen, 2014; Verhaeghen & De Meersman, 1998). Rather than asking whether there is one slowing mechanism, the question is now how many dissociations exist.

2.6 Visuospatial Processing Speed Tasks

Processing speed can be simply measured by recording the time it takes to perform a task. Because response times (RTs) are measured using a ratio scale with a true zero point, it is possible to directly compare means and standard deviations from different tasks or different participant groups, which is useful in establishing performance norms for different age groups or task domains. Importantly, the tasks used to assess processing speed must meet specific criteria to ensure that RTs reflect the speed of processing of the desired component or mechanism being measured, and in interpreting age-related differences in a particular component, differences in other components, must also be considered.

When examining dissociations in processing speed between domains or different classes of stimuli, it is the cognitive processing stage (i.e., the central component) which is of interest, although for some purposes, it may be useful to divide this component into subcomponents. Notably, Cerella (1990) found that slowing was greater for tasks that relied more on cognitive processing than for tasks that involved a greater motor component, which implied that central and peripheral processes had different rates of slowing and provided the preceding explanation for negative intercepts. For this reason, it is important that comparisons are made only between tasks that have similar sensorimotor requirements (e.g., all tasks require perception of a visual stimulus and a button-pressing response).

Many previous studies investigating processing speed within the visuospatial domain have relied on information-processing tasks that do not contain a working memory component, but some have also utilized recognition memory tasks (e.g., Hildebrandt et al., 2013; Hildebrandt et al., 2011). Due to the fact that older adults experience impairments on tasks involving memory, recognition tasks could produce latencies that misrepresent the time it takes to process the information and come to a decision because speed measures on recognition tasks also measure how long it takes older adults to retrieve information. Furthermore, there is some research suggesting that delayed-matching-to-sample tasks have a differential slowing pattern than simultaneous matching tasks (Swearer & Kane, 1996) and there is a risk that information may be lost or was subject to decay over the retention interval which would result in longer latencies and lower accuracy (Grady et al., 1995).

Within the visuospatial domain, tasks requiring matching, visual search, mental rotation, and choice reaction time have been established in the literature as pure information processing tasks (Cerella, Poon, & Fozard, 1981; Hildebrandt et al., 2013; Hildebrandt et al., 2011; Hoyer, Rebok, & Sved, 1979; Verhaeghen, 2014; Simon & Pouraghabagher, 1978; Swearer & Kane, 1996). All of these tasks are considered to measure visuospatial processing and have certain characteristics in common; the peripheral processing component is minimized and the stimuli are visual in nature and do not require any verbal processing (although some stimuli can be 'verbalized' more than other stimuli).

On choice reaction time tasks, two (or more) choices are presented and participants must press one key corresponding to a specified characteristic. For example, participants may be required to press one of two keys indicating whether the stimulus is red or green or they may have to choose from four responses to indicate the portion of the visual field in which the stimulus was presented (Ulrich, Mattes, & Miller, 1999; Verhaeghen, 2014). Often, choice reaction time tasks are compared to a baseline condition consisting of simple reaction time tasks which present a single stimulus that participants must respond to as soon as the stimulus is perceived; differences in latency between choice reaction time and simple reaction time reflect the time needed for processing requirements in choice reaction time but not needed for the processing required to detect a stimulus (Ulrich et al., 1999).

Simple matching tasks involve comparing two stimuli and deciding whether they are identical; more difficult versions of this task can be created by increasing the similarity between the two stimuli. Matching tasks are very common in the literature and are also often used to test recognition after a short retention interval (Boutet & Faubert, 2006; Hildebrandt et al., 2011). A visual search task is similar to a matching task but requires the participant to search for a specific stimulus (the ‘target’) from an array, rather than from two stimuli, or decide whether at least one stimulus from the array contains (or lacks) a given characteristic. On target present trials, participants must search, on average, half of the objects contained in the array; larger arrays lead to longer response times because more objects must be searched. An object classification task may, for example, ask participants to decide whether two objects that differ in size are otherwise identical or belong to the same category of objects. One of the benefits of simple matching, visual search tasks, and object classification tasks is that, when comparing performance on tasks using different classes of stimuli, tasks with equivalent requirements can be created for each stimulus domain. Past studies investigating differences between face and object processing have compared performance on parallel tasks that differed only in the stimulus domain (e.g., Hildebrandt et al., 2013); for instance, a visual search task may consist of deciding whether all faces are identical or whether there is one face that is different, and the equivalent task from the object domain would be identical except that the stimuli would consist of objects instead of faces.

Other tasks have also been utilized to assess cognitive processing speed and slowing in the visuospatial domain. For example, on mental rotation tasks participants are shown two objects and must decide if they are identical; on identical trials, one object is rotated at a given angle. Difficulty can be increased by increasing the angle of rotation, and response latencies vary linearly with the angle of rotation on these tasks (Shepard & Metzler, 1971). A variety of visuospatial processing tasks (e.g., visual search, abstract matching, and shape classification) were included in Lawrence and colleagues’ study (1998) to confirm the dissociation between the rate of slowing of verbal and non-verbal processing. For example, an abstract matching task, similar to a task used by Hoyer and colleagues (1979), required participants to compare two arrays consisting of objects, judge them on four dimensions (e.g., shape, color, etc.), and choose the array that was the better match for a sample array. Importantly, what appears to be critical for measuring visuospatial processing speed is that tasks have minimal peripheral (sensory and motor) components and that task difficulty can be manipulated by varying simple stimulus characteristics (e.g., number of items in a visual search task or stimulus similarity on matching tasks). The latter characteristic is critical because it makes it possible to create different kinds of speeded tasks (e.g., face and object processing tasks) matched on difficulty for younger adults on which the performance of older adults can be compared.

In the current study, it was important that the selected tasks were easy to instantiate as analogous tasks in both the object and the face domain and that the tasks be structurally similar to tasks that have been used to measure processing speed in previous studies. To this end, I relied on tasks requiring discrimination of identity or attributes and tasks relying on ‘family’ resemblance judgments to measure processing in the face and object domains in younger and older adults.

Chapter 3: The Current Study

The purpose of the current study was to test the hypothesis that age-related cognitive slowing proceeds at a different rate for face processing compared to slowing associated with object processing, that is, a differential slowing rate hypothesis. Because of the multitude of research showing that there are qualitative differences between face and object processing (i.e., faces rely more on holistic processing) and that neural specificity for faces is retained in older adults (Hildebrandt et al., 2013; Hildebrandt et al., 2011; Boutet & Faubert, 2006; Daniel & Bentin, 2012), the hypothesis was that there exists a dissociation between the rates of slowing for face and object processing.

To test the differential slowing rate hypothesis, I developed two different batteries of tasks that varied primarily in the type of stimuli and were administered to a large group of younger and older adults via online testing. A set of standardized faces was created, most of which did not include hair cues so that attention would be directed exclusively on facial information that distinguishes one face from another. Some research suggests that hair is an important feature that aids in face recognition (Wright & Sladden, 2003). Including hair cues may contribute to the own gender bias for faces, the finding that participants perform better with faces of their own gender. In a study by Wright and Sladden (2003), both male and female participants were more accurate when shown faces of their own gender that included hair, but the effects were smaller for cross gender identification. Thus, in the current study, hair was excluded in tasks that required comparisons of non-identical faces because perceptual processing of internal configurations of face features was of primary interest. For tasks in which hair did not aid or impede the completion of the task because comparisons were made between two versions of the same face (e.g., judgments of masculinity and femininity), I retained the hair to increase the ecological validity of such comparisons. The non-face stimuli used in all the objects tasks consisted of ‘Attneave’ shapes, which have been established in the literature as being representative of the spatial domain (Attneave & Arnoult, 1956; Attneave, 1957; Collin & Mullen, 2002).

Classification based on categorical information such as age, race, and sex may be a parallel function to face processing; there is evidence that outgroup faces (i.e., faces belonging to a race or age category different from one’s own) are classified more quickly (Levin, 2000; Meissner & Brigham, 2001; Valentine, 1991, 2001). Thus, it may be the case that such judgments do not show the same degree of age-related slowing as other individuation tasks. For these reasons, abstract age-matching tasks (e.g. are both these faces the same age?) and tasks that rely on simple sex or race classifications (e.g., is this face male or female?) were avoided.

The argument for including tasks requiring attribute judgments (i.e., femininity, masculinity, and symmetry) stems from the fact that in these cases the same individual’s face was altered, and the two very similar faces must be discriminated, not for identity, but rather based on femininity, masculinity, or symmetry. These tasks did not require accessing an abstract category such as sex (e.g., determining if two different faces were female). Instead, participants judged different versions of the same face on a particular attribute (e.g., symmetry).

All face tasks were created to have an equivalent or close to equivalent counterpart in the object domain. For instance, one of the face tasks required participants to choose which composite face, out of two faces, most closely resembled the sample composite face presented above the two options, and the corresponding object task required participants to indicate which object, out of two objects, was most similar to the sample object. The two batteries of tasks consisted of speed-of-processing tasks that varied in difficulty and in the time it took to process the information. Although it was expected that individual differences would affect perceived task difficulty, the tasks were created with the intention that the correct answer should be readily apparent. Response times and accuracy were recorded for each task.

Although slowing of peripheral and motor processes is less pronounced than in central processes (Cerella, 1985), it is significant enough that measures should be taken to ascertain that any deficits obtained are due to the cognitive demands of the task. To reduce the possibility of confounding age-related slowing in peripheral processes with cognitive slowing, all tasks in the current study were standardized to be alike in their perceptual and motor requirements. All tasks consisted of a visual stimulus and pressing one of two keys to make a response of “yes” or “no,” “present” or “absent,” or “left” or “right.”

It must also be noted that whenever tasks require face recognition, even in tasks of immediate recognition, there is at least a small memory component present. Age-related decrements on face memory tasks are well-documented, and it is not clear how an added memory requirement may interfere with slowing during face processing (D'Argembeau & Van der Linden, 2004; Hildebrandt et al., 2010; Memon et al., 2002; Searcy et al., 1999). Thus, relying on recognition tasks could be problematic. To address this issue, none of the tasks in the current study required memorization or recognition.

Another problem that might occur is the possibility of obtaining a false dissociation due to strategic differences between older and younger adults. To minimize this possibility, there were 20 tasks in each domain, which makes it unlikely that the same strategy could be used for all tasks. For instance, judging the symmetry of a face, the similarity of a face to a target, and determining whether two faces are identical or different all tap into face processing but are likely to require different strategies. It is unlikely that older adults could perform these tasks using a different strategy than younger adults on all tasks.

All data were collected online on MTurk.com, which has been proven to be a reliable method for collecting cognitive data (Bui, Myerson, & Hale, 2015; Rand, 2012; Woo, Keith, & Thornton, 2015). In fact, although one might have questioned whether one could measure RTs accurately enough using the internet, or whether the older adults one can recruit online would be representative enough, relevant laboratory findings of benchmark effects such as age-related declines in processing speed and greater decline in spatial processing than in verbal processing have been replicated using online samples (Bui et al., 2015).

Chapter 4: Methods

4.1 Participants

Two batteries of tasks were administered to 150 participants: 53 young adults recruited from the Washington University Psychology Subject Pool who received course credit for participation, 45 young adults and 52 older adults recruited using Amazon Mechanical Turk (MTurk) who were paid $10. Of these 150 participants, all but 10 completed all 16 tasks. As detailed in the Results section, after applying an accuracy inclusion criterion, only 110 participants (40 young adults from Washington University, 34 young adults from MTurk, and 36 older adults from MTurk) remained in the sample. Demographic characteristics are provided for the two age groups in Table 4.1. Inspection of Table 4.1 shows that the two age groups differ in terms of the distribution of educational attainment. Among the young adults: 25% have only a HS degree, 50% have some College (this includes WU students who will graduate in a few years and move into the next category), and 25% have an UG degree. In contrast, among the older adults: 20% have only a HS degree, 20% have some College, 50% have an UG degree, and 10% have an Advanced degree. In addition, the young adult group includes Asian Americans whereas the older adult group does not. Turning to Table 4.2, the differences in educational attainment for the two young adult groups reveals more college graduates among the MTurk group, but this is in part due to the fact that the Washington University students are currently enrolled in college. Similar to the differences between the younger and older groups, the Washington University sample included a much higher proportion of Asian Americans relative to the MTurk sample.

Table 4.1 Demographics as a function of Age Group

Variable	Age Group: Young Adults (n=74)	Age Group: Older Adults (n=36)
Age	21.3 (1.9)	63.3 (4.7)
Sex	48 Females (65%)	21 Females (58%)
Race		
Caucasian	56	32
African American	4	3
Asian American	14	1
Ethnicity		
Hispanic	4	1
Education		
High School	17	7
Some College	34	7
College Grad	23	19
Graduate School	0	3

Table 4.2 Demographics for Young Adults as a function of Sample Source.

Variable	Source: WU (n=40)	Source: MT (n=34)
Age	20.5 (1.5)	22.2 (1.9)
Sex	29 Females (73%)	19 Females (56%)
Race		
Caucasian	25	31
African American	3	1
Asian American	12	2
Ethnicity		
Hispanic	1	3
Education		
High School	8	9
Some College	26	8
College Grad	6	17
Graduate School	0	0

Note: WU = Washington University Undergraduate Sample, MT = MTurk Sample

4.2 Stimuli

4.2.1 Face Battery

All stimuli in this battery consisted of young, Caucasian, male and female faces. Photographs of unique male and female faces were taken from various databases: Chicago Face Database, Berlin Faces, the London Set, and the Lifespan Database (DeBruine & Jones, 2017; Ebner, Riediger, & Lindenberger, 2010; Ma, Correll, & Wittenbrink, 2015; Minear & Park, 2004). All stimuli were modified using Photoshop, PsychoMorph, and Webmorph software. Modification of the faces included cropping and desaturation, as well as manually adjusting the brightness and contrast in photoshop to achieve subjective uniformity across faces. For all tasks, all faces were presented in grayscale.

Some of the face tasks used original faces (e.g., Task 1: Condition 1), in which features and identity were unaltered. A total of 200 original male and female faces were used throughout the experiment. Other tasks required altering specific features (e.g., Task 6) which were edited in Photoshop, which has tools to enlarge and rotate parts of an image (or an entire image) to a precise degree or percent. The clone stamp tool in Photoshop was used to smooth out the edges of features that were altered and to remove face jewelry. In Task 6, perfectly symmetrical faces were created by splitting faces in half vertically and then copying and pasting the mirror image to create a symmetric face. Faces were not repeated across tasks; participants saw each unique face only once, but face composites were created from original faces that may have been used in a different task.

On tasks that required face composites, faces were averaged together with Webmorph software (DeBruine, 2017) which uses established methods that have been widely used in studies of face perception (Jones et al., 2005; Perret et al., 1998; Rowland & Perret, 1995; Welling, Jones, DeBruine, 2008; Welling et al., 2007). Each face was delineated at 90 points (i.e., various face locations were precisely tagged: the inside corner of the left eye, the outer corner of the left eye, the top middle of the left eye, the bottom middle of the left eye, the left pupil, etc.) to ensure that two or more faces averaged together were aligned and the averaged calculations were based on the physical size and location of each face's features (see Figure 4.1). The stimuli in Task 4 and 5 were delineated at 189 points.

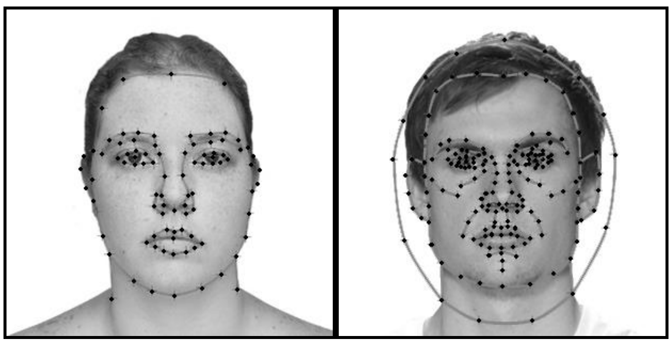

Figure 4.1. An example of a face delineated at 90 points (left) and a face delineated at 189 points (right).

Face stimuli in Task 4 and 5 were altered by feminizing and masculinizing the faces using Webmorph software (DeBruine, 2017). Objective masculinization and feminization of male and female faces was achieved by adding or subtracting 50% of the linear differences in 2D shape between a male and female face prototype (see Figure 4.2). The prototypes were symmetrized composite images created from 20 Caucasian male faces for the male prototype and 20 Caucasian female faces for the female prototype from the London Set face database which were averaged on shape, texture, and color (DeBruine & Jones, 2017). The computer algorithm transformed the faces in shape by 50% relative to the differences between the two prototype faces; color and texture were not altered. To illustrate, the distance between the eyes and eyebrows was greater in the female prototype than in the male prototype; when a unique face was masculinized by 50%, the eyes and eyebrows were shifted by 50% of the difference between the female and male prototype, resulting in an altered version of the face in which the eyebrows were closer to the eyes regardless of the starting position of the features. This process is not the same as averaging an original face toward the prototype. For example, the male prototype had a larger jaw and eyebrows closer to the eyes; masculinization always resulted in a larger jaw and eyebrows closer to the eyes, and feminization had the opposite effect. Male and female faces were masculinized and feminized in the same way. Previous research using this method has shown that the manipulation produces faces that are perceived as more masculine or more feminine in the intended direction (DeBruine et al., 2006; Jones et al., 2005; Perret et al., 1998; Welling et al., 2007). Because all faces were manipulated in the same way to produce masculine and feminine versions of an original face, masculinized faces always had thicker brows than the original, femininized faces had smaller jaws, and so on. It is possible that participants could adopt a strategy focusing on one feature (e.g., thinner or thicker brows) rather than perceiving the entire face to determine masculinity or femininity. This problem, however, has not been reported previously, and it would be difficult to alter perceived masculinity or femininity without altering the shape of features that have been demonstrated to affect the perception of masculinity and femininity. Varying which features are masculinized or feminized across trials could also affect perceived masculinity and femininity because some features are given more weight when making judgments about masculinity and femininity (Mogilski & Welling, 2018). Cropping the faces would prevent participants from choosing the larger face when judging masculinity and vice versa when judging femininity but perception of masculinity and femininity is based on judgments of the entire face, including the outline of the jaw (Mogilski & Welling, 2018). Removing the information provided by the shape of the jaw could alter perceived masculinity and femininity or increase the difficulty of the task. Importantly, participants were simply asked to choose the more masculine or feminine face and were not told which features to attend to.

Figure 4.2. The male and female face prototypes used to masculinize and feminize faces.

4.2.2 Object Battery

All object stimuli in this battery were Attneave shapes created following the general guidelines outlined by Attneave and Arnould in 1956 using Matlab and photoshop. Specifically, the objects were solid black, 2-D polygons against a white background. To create the objects, a new program, NewShapeFamily.m, was written for Matlab which was based on the program ShapeFamily.m by Collin and Mullen (2002). The new program was written with the current demands of this study in mind. With the NewShapeFamily.m toolbox, the degree of similarity between objects can be manipulated to create ‘families’ of objects, the number of members in each family can be specified, and close and distant ‘relatives’ based on the same prototype can be created. I used an algorithm that shifted the corners of a shape by a specific percentage to create family resemblance between shapes (see Collin & Mullen, 2002). The images created were all the same size but the size of the polygons within the white background was not controlled. Shifting the corners of a prototype object resulted in changes to the area of the object, but a higher degree of similarity between family members resulted in objects that were closer in size. All the objects in the object battery had six sides except for the objects used in the symmetry task. Photoshop was used to skew and rotate the shapes as needed for each task.

The decision to use Attneave shapes was partially based on the ease with which these shapes can be created and uniformly manipulated, which would have been difficult to do using other objects (e.g., houses). For example, it would be difficult to create houses that varied precisely in the amount of similarity to a house prototype. Whereas original faces can be morphed to create a new face that is similar to an old face by a specified percent, no such software exists to create a house, or another object, that is 50% similar to an original house stimulus. Although skin textures can be morphed together to create a texture that falls between two faces, different object textures, such as wood and metal, cannot always be morphed to form a realistic texture. Finally, whereas there are several face databases and many front-facing portraits available online, finding a large set of pictures of objects that were taken from a similar angle and are not obstructed by other objects is a difficult, if not impossible, task. Additionally, because all object stimuli were original and had irregular forms, it ensured that processing was strictly visuospatial. The shapes were not easily nameable, and it is very unlikely that participants would choose to use verbal labels to process the stimuli instead of perceptual processing.

4.3 General Method

Participants in this study were administered two batteries of tasks (one using face stimuli and one using object stimuli) online using their personal computer. The tasks were all programmed in flash using Adobe Flash Professional CS5 and uploaded online using Bluehost webpage hosting.

Each of the two batteries consisted of eight tasks and a total of 20 conditions (see Tables 4.3 and 4.4). Notably, for each battery, there were tasks that required participants to make same-different judgments, to make forced-choice decisions, to make stimulus attribute judgments, and to visually search displays of multiple stimuli.

All participants were administered the tasks in a random order. The tasks were not blocked by battery. After consenting to participate in the study, each participant was assigned to a random order in which to complete each task. All trials in each task were fully randomized across task conditions with the exception of Task 2. In Task 2, participants were asked to determine whether all the faces presented in an array were identical or if one was different; on different trials in Condition 1 and 3, the different face was unrelated to the other faces in the array but in Condition 2 and 4, the different face was 50% similar to the other faces. Research on the perception of morphed faces suggests that there is an acceptable degree of ‘deformity’ that is permissible before a face is perceived as different; in other words, naturally occurring variations in a face do not necessarily signify a change in identity and no change in identity is perceived between highly similar morphed faces (Beale & Keil, 1995; Kikutani, Roberson, & Hanley, 2010; Rotshtein, Henson, Treves, Driver, & Dolan, 2005). There is also evidence that discrimination based on identity changes and discrimination based on physical changes are distinct abilities that rely on different brain regions (Rotshtein et al., 2005), and relying on a strategy that is sensitive only to changes in identity may overlook physical changes. The morphed faces used in this task were only 50% similar but it is possible that participants might choose to rely on either an identity discrimination strategy or a physical discrimination strategy which could introduce unwanted effects. It is unclear how discriminating unfamiliar faces and intermixing trials with different discrimination thresholds (i.e., discriminating unrelated faces and similar faces) in a speeded visual search task would impact performance. To avoid the small possibility that differences in discrimination threshold would impact overall performance, the conditions using unrelated faces (Conditions 1 and 3) and similar faces (Conditions 2 and 4) were tested separately, and to maintain symmetry, the corresponding conditions from Object Task 2 were tested separately as well. The reasoning behind testing both conditions in Task 1 together was that in this task the participants' attention was directed at only two faces (or objects) in each trial and, on different trials, the task required discriminating between two non-identical stimuli. Because Task 7 was a forced choice task in which participants had to decide which of two faces (or objects) was most similar to a third face, all conditions were presented together. See Table 4.3 and Table 4.4 for characteristics of all tasks.

Table 4.3 Characteristics of all Tasks in the Face Task Battery

Face Task Battery

Task	Type of Task	Type of Judgment	Cond	Question
Face Task 1	Identity	Same-Different	2	Are these two faces the same or different?
Face Task 2	Identity	Visual Search	4	Are all of the faces the same or is one different?
Face Task 3	Identity	Forced Choice	1	Which of the frontal views is the person in the angled-view face?
Face Task 4	Attribute	Masculinity	2	Which version of this male face is more masculine?
Face Task 5	Attribute	Femininity	2	Which version of this female face is more feminine?
Face Task 6	Attribute	Symmetry	3	Which version of this face is more symmetrical?
Face Task 7	Resemblance	Forced Choice	4	Which of the bottom faces is most similar to the top face?
Face Task 8	Resemblance	Visual Search	2	Do all of the faces look related or is one face unrelated?

Note: Cond = the number of conditions, See text for details about how the faces were modified and the different conditions were created for each task.

Table 4.4 Characteristics of all Tasks in the Object Task Battery

Object Task Battery

Task	Type of Task	Type of Judgment	Cond	Question
Object Task 1	Identity	Same-Different	2	Are these two objects the same or different?
Object Task 2	Identity	Visual Search	4	Are all of the objects the same or is one different?
Object Task 3	Identity	Forced Choice	1	Which of the bottom objects is a rotated version of the top object?
Object Task 4	Attribute	Width	2	Which version of this object is wider?
Object Task 5	Attribute	Height	2	Which version of this object is taller?
Object Task 6	Attribute	Symmetry	3	Which version of this object is more symmetrical?
Object Task 7	Resemblance	Forced Choice	4	Which of the bottom objects is most similar to the top object?
Object Task 8	Resemblance	Visual Search	2	Do all of the objects look related or is one object unrelated?

Note: Cond = the number of conditions, See text for details about how the objects were modified and the different conditions were created for each task.

As can be seen in Tables 4.3 and 4.4, there were three different types of tasks in each battery: 1) strict identity tasks (e.g., Are these two faces/objects the same or different?), 2) attribute judgment tasks which required judging different versions of the same face/object (e.g., Which version of this face/object is more symmetrical?), 3) family resemblance tasks (e.g., Do all of the faces/objects look related or is one face/object unrelated?). For all tasks, instructions on how to complete the task along with examples appeared on the screen, and participants were allowed to view the instructions as long as they needed to by clicking the 'forward' or 'back' button on the screen. Once the participant was ready to begin the task, the participant clicked the 'continue' button on the screen to move onto the tasks. All participants completed the tasks in a random order that was assigned to them after they consented to be in the study. Participants could complete the tasks one by one in their own time. Each task took between 5 to 15 minutes to complete and the entire experiment lasted between 1.5 to 2 hours.

On all tasks, every trial began with a fixation cross presented for 500 ms. After this, a single screen, which contained all the necessary stimuli for that trial, appeared and remained visible until the participant made a response or 15 seconds had elapsed. Responses were recorded and response times were also measured.

4.4 The Face Domain

4.4.1 Strict Identity Tasks in the Face Domain

Face Task 1: Same/Different Face Identity Judgment Tasks

In this task, participants had to decide whether two faces presented side by side were identical or different. Participants pressed either 'z' or '/' on their keyboard to respond 'same' or 'different.'

Two faces were cropped and placed inside an oval to remove hair and clothing cues. The face on the right was reduced to 60% of the size of the face on the left and the top portion of the head was cropped so that participants would have to check the identity of each face to make the same/different judgment. Each condition consisted of 20 trials; there were 10 same trials and 10 different trials. For both the 10 same trials and the 10 different trials, half were female faces and the other half were male faces.

Condition 1: On same trials, one unique face was used. On different trials, two unique faces were used (see Figure 4.3).

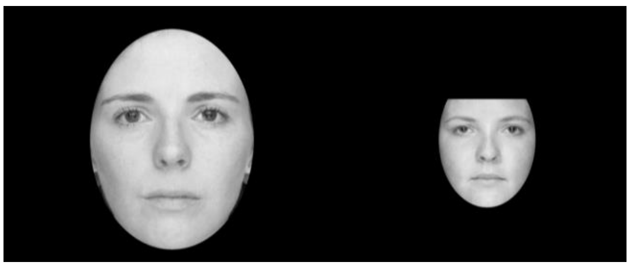

Figure 4.3. An example of a 'different' trial from Face Task 1, Condition 1.

Condition 2: This condition involved increasing the difficulty of discriminating the two faces on different trials. Thus, as in Condition 1, on same trials, a unique face was used; however, the face was a composite created from 50% face A and 50% face B. On different trials, two composite faces, which were 50% similar (instead of 0% similarity as in Condition 1), were shown. The first face was created from 50% face A and 50% face B and the second face was created from 50% face A and 50% face C (see Figure 4.4).

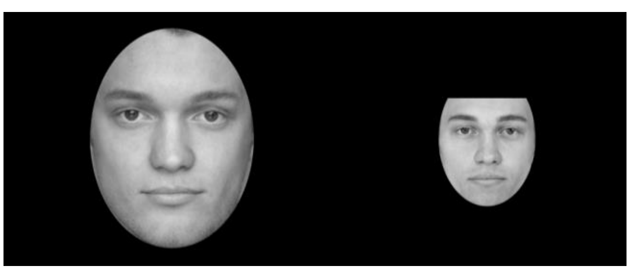

Figure 4.4. An example of a 'different' trial from Face Task 1, Condition 2.

Face Task 2: Visual Search Face Identity Task

In this task, participants were required to conduct a visual search to determine if all faces in the array were the same or if there was one face that was different. Participants pressed either 'z' or '/' on their keyboard to respond 'same' or 'different.'

All the faces used in the array were cropped and placed inside an oval to remove hair and clothing cues. Each condition consisted of 20 trials; there were 10 same trials and 10 different trials. Of the 10 same trials and the 10 different trials, half consisted of female faces and five consisted of male faces. Condition 1 and Condition 3 were presented together, and Condition 2 and Condition 4 were presented together.

Condition 1: Faces were presented in an array of four. On same trials, one unique face was used and all four faces in the array were identical. On different trials, two unique faces were used and one of the four faces in the array was different (see Figure 4.5).

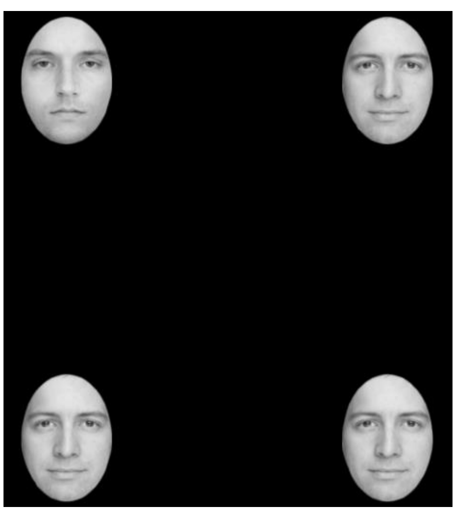

Figure 4.5. An example of a 'different' trial from Face Task 2, Condition 1.

Condition 2: As in Condition 1, faces were presented in an array of four. However, each face was a composite created by averaging two faces, resulting in a single face that was 50% face A and 50% face B. On same trials, one unique composite face was used and all four faces in the array were identical (thus these trials were essentially the same as those in Condition 1). On different trials, two composite faces, which were 50% similar, were used; one of the four faces in the array was different (see Figure 4.6). That is, one face (which appeared in three of the positions) was composed of 50% face A and 50% face B and the fourth face was composed of 50% face A and 50% face C.

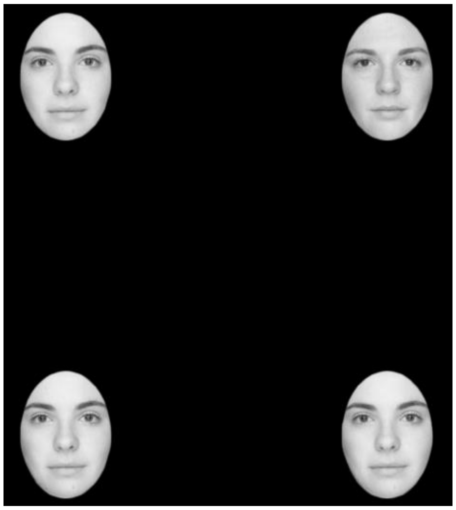

Figure 4.6. An example of a ‘different’ trial from Face Task 2, Condition 2.

Condition 3: Faces were presented in an array of six. As in Condition 1, on same trials, one unique face was used and all faces (in this case six) in the array were identical. On different trials, two unique faces were used and one of the six faces in the array was different (see Figure 4.7).

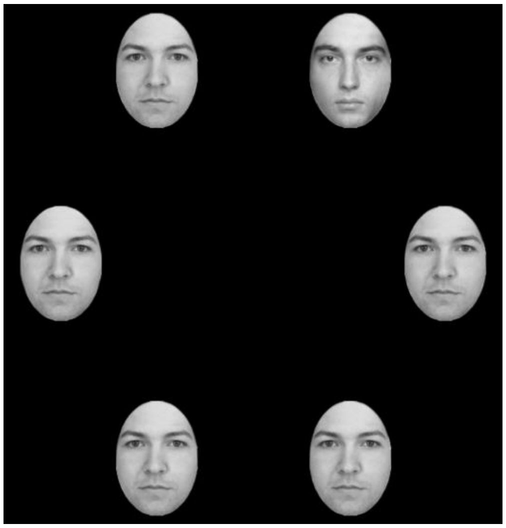
Figure 4.7. An example of a ‘different’ trial from Face Task 2, Condition 3.

Condition 4: As in Condition 3, faces were presented in an array of six. However, each face was a composite created by averaging two faces resulting in a single face that was 50% face A and 50% face B. On same trials, one unique composite face was used and all six faces in the array were identical (thus these trials were essentially the same as those in Condition 3). On different trials, two composite faces, which were 50% similar, were used and one of the six faces in the array was different (see Figure 4.8). That is, one face (which appeared in five of the positions) was composed of 50% face A and 50% face B and the sixth face was composed of 50% face A and 50% face C.

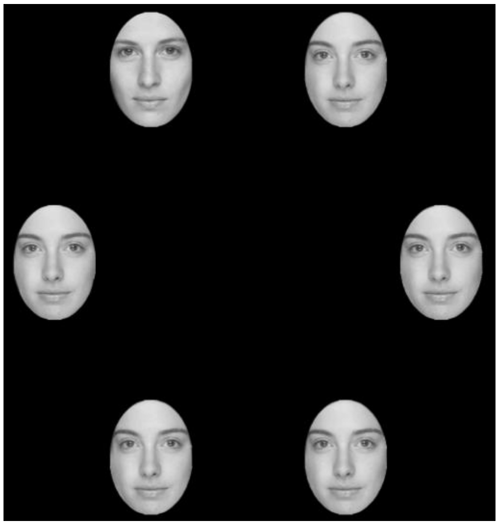

Figure 4.8. An example of a ‘different’ trial from Face Task 2, Condition 4.

Face Task 3: Forced Choice Face Identity task

This task was a more difficult version of a discrimination task and included face stimuli depicted from a frontal view as well as at a 45° angle. A sample face was presented at a 45° angle above two other faces (the matching face and a foil), which were shown from a frontal view. Twenty trials (10 male faces; 10 female faces) were presented. Participants had to determine which of the two faces, ‘left’ or ‘right,’ depicted the same face as in the sample (see Figure 4.9). Participants pressed either ‘z’ or ‘/’ on their keyboard to respond ‘left’ or ‘right.’

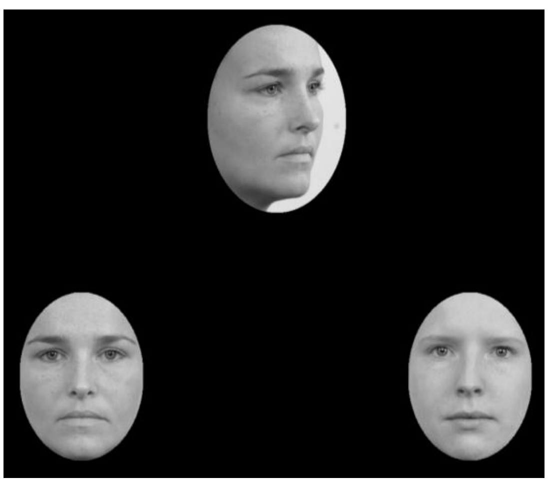

Figure 4.9. An example of a trial from Face Task 3. The correct match is the face on the left.

4.4.2 Attribute Judgment Tasks in the Face Domain

Face Task 4: Masculinity Judgment Task

In this task, participants had to decide which male face was more masculine. There were 20 trials in each condition. Participants pressed either ‘z’ or ‘/’ on their keyboard to respond ‘left’ or ‘right.’

Using Webmorph software (DeBruine & Jones, 2017), a unique male face was manipulated to create a masculinized version of the face and a feminized version of the face resulting in three faces: the original face, the masculinized version, and the feminized version. This software allowed for a uniform manipulation of all faces (i.e., all faces were masculinized or feminized to the same degree). Masculinization resulted in altered male faces that had a thicker neck, thicker brows, brows that were closer to the eyes, a forehead that was less rounded, and a wider jaw. Feminization resulted in altered male faces that had a thinner neck, thinner brows, more space between the eyes and brows, a more rounded forehead, and a thinner, more pointed jaw.

Condition 1: Participants had to decide which version of the face was more masculine when given a choice between the feminized and masculinized versions of the face (see Figure 4.10).

Figure 4.10. An example of a trial from Face Task 4, Condition 1. The face on the right is more masculine.

Condition 2: Difficulty was increased in this condition by increasing the similarity between the two faces and thus making the discrimination more difficult. Participants had to decide which version of the face was more masculine when given a choice between the original and masculinized version of the face (see Figure 4.11).

Figure 4.11. An example of a trial from Face Task 4, Condition 2. The face on the right is more masculine.

Face Task 5: Femininity Judgment Task

In this task, participants had to decide which female face was more feminine. There were 20 trials in each condition. Participants pressed either ‘z’ or ‘/’ on their keyboard to respond ‘left’ or ‘right.’

The same software and procedure as in Face Task 4 were followed to create the stimuli for Face Task 5. A unique female face was manipulated to create a masculinized version of the face and a feminized version of the face resulting in three faces: the original face, the masculinized version, and the feminized version. Masculinization resulted in altered female faces that had a thicker neck, thicker brows, brows that were closer to the eyes, a forehead that was less rounded, and a wider jaw. Feminization resulted in altered female faces that had a thinner neck, thinner brows, more space between the eyes and brows, a more rounded forehead, and a thinner, more pointed jaw.

Condition 1: Participants had to decide which version of the face was more feminine when given a choice between the feminized and masculinized version of the face (see Figure 4.12).

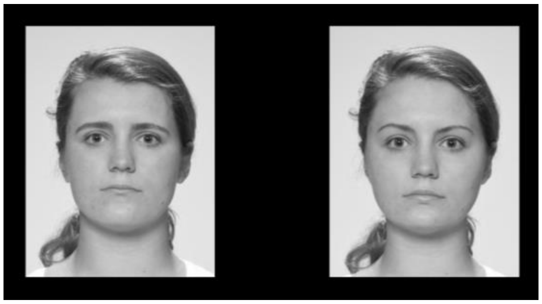

Figure 4.12. An example of a trial from Face Task 5, Condition 1. The face on the right is more feminine.

Condition 2: Participants had to decide which version of the face was more feminine when given a choice between the original and feminized version of the face (see Figure 4.13).

Figure 4.13. An example of a trial from Face Task 5, Condition 2. The face on the left is more feminine.

Face Task 6: Symmetry Judgment Task

In this task, participants had to decide which face was more symmetrical. There were 20 trials in each condition. Participants pressed either 'z' or '/' on their keyboard to respond 'left' or 'right.'

Every trial consisted of one unique face; one version of the face was manipulated to be perfectly symmetrical and, to create the less symmetrical face, the perfectly symmetrical face was slightly distorted (details provided below). Using Photoshop, the symmetrical face was created by splitting a face in half, copying and flipping one half of the face to form a mirror copy, and then pasting that half on the opposite side to form a complete face. Half of the trials were male faces and the other half were female faces.

Condition 1: In the easiest condition of this task, the less symmetrical face had three changes made. One eye was enlarged to 112% of its original size and rotated 5°. The mouth was also rotated 5°. Participants had to decide which face was more symmetrical (see Figure 4.14).

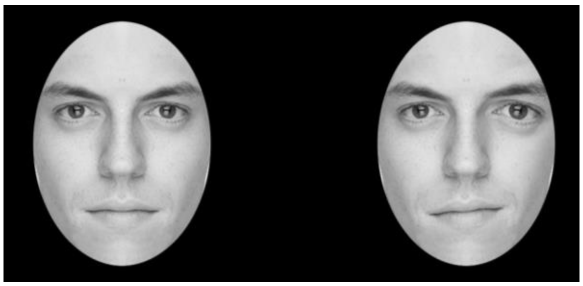

Figure 4.14. An example of a trial from Face Task 6, Condition 1. The face on the left is more symmetrical.

Condition 2: In this condition , the less symmetrical face had three changes made but the degree of change was slightly smaller for all three manipulations relative to the changes in Condition 1. One eye was enlarged to 110% of its original size and rotated 4°. The mouth was also rotated 4°. Participants had to decide which face was more symmetrical (see Figure 4.15).

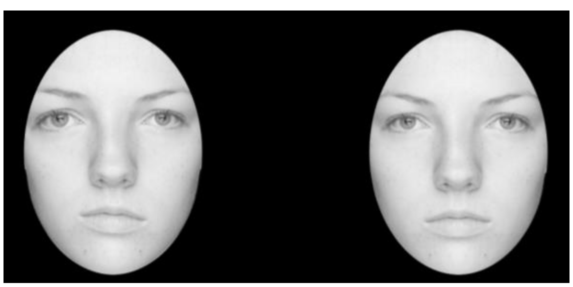

Figure 4.15. An example of a trial from Face Task 6, Condition 2. The face on the right is more symmetrical.

Condition 3: In the final condition of this task, the less symmetrical face had three changes made but the degree of change was slightly smaller for all three manipulations relative to the changes in Condition 2. One eye was enlarged to 108% of its original size and rotated 3°. The mouth was also rotated 3°. Participants had to decide which face was more symmetrical (see Figure 4.16)

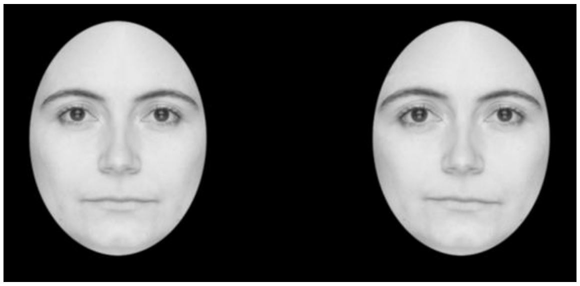

Figure 4.16. An example of a trial from Face Task 6, Condition 3. The face on the left is more symmetrical.

4.4.2 Family Resemblance Tasks in the Face Domain

Face Task 7: Forced Choice Family Member

In this task, a sample face was presented above two composite faces. Participants had to decide which of the two faces most resembled the sample face. There were 20 trials per condition and half of the trials were male faces and the other half were female faces. Participants pressed either ‘z’ or ‘/’ on their keyboard to give a response of ‘left’ or ‘right.’

Condition 1: The sample face was a unique face ‘A.’ One of the two composite faces that participants had to choose from was not similar at all to the sample face; the foil was composed of two faces that were both different from the sample. The correct face option was 75% similar to the sample face; the target was composed of the sample face and an additional face (i.e., 75% face ‘A’ and 25% face ‘B’). See Figure 4.17 for a sample trial.

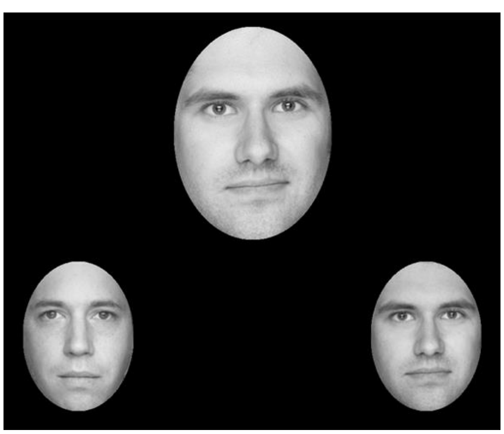

Figure 4.17. An example of a trial from Face Task 7, Condition 1. The face on the right is a closer match.

Condition 2: The sample face was a unique face, face 'A.' One of the two faces that participants had to choose from was slightly similar (25%) to the sample face; the foil was created by combining the sample face with another face (i.e., 25% face 'A' and 75% face 'B'). The correct face option was 75% similar to the sample face; the target was composed of the sample face and an additional face (i.e., 75% face 'A' and 25% face 'C'). See Figure 4.18 for a sample trial.

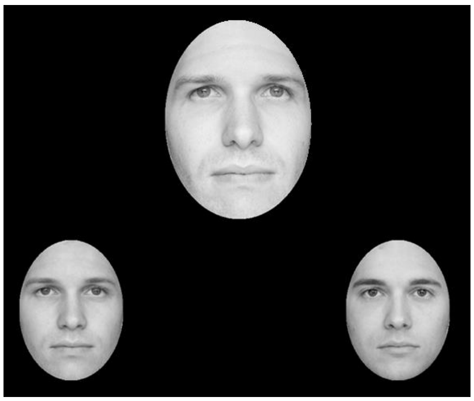

Figure 4.18. An example of a trial from Face Task 7, Condition 2. The face on the left is a closer match.

Condition 3: The sample face was a unique face, face 'A.' One of the two composite faces that participants had to choose from was not similar at all to the sample face and was composed of two faces that were both different from the sample. The correct face option was similar to the sample face because it was composed of the sample face and an additional face (i.e., 50% face 'A' and 50% face 'B'). See Figure 4.19 for a sample trial.

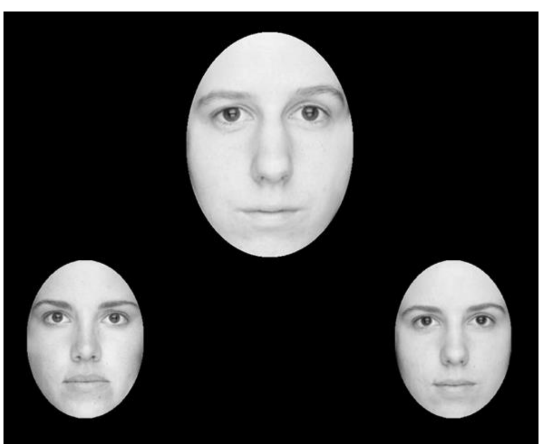

Figure 4.19. An example of a trial from Face Task 7, Condition 3. The face on the right is a closer match.

Condition 4: The sample face was a unique face, face ‘A.’ One of the two faces that participants had to choose from was slightly similar (25%) to the sample face because it was created by combining the sample face with another face (i.e., 25% face ‘A’ and 75% face ‘B’). The correct face option was similar to the sample face because it was composed of the sample face and an additional face (i.e., 50% face ‘A’ and 50% face ‘C’). See Figure 4.20 for a sample trial.

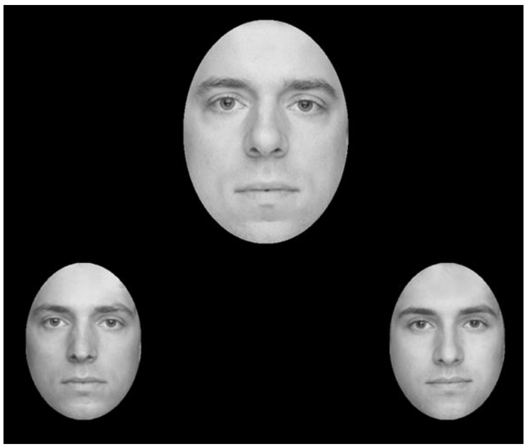

Figure 4.20. An example of a trial from Face Task 7, Condition 1. The face on the left is a closer match.

Face Task 8: Visual Search Family Member

In this task, participants were presented with an array of faces and had to decide whether all the faces belonged to the same family (i.e., could these individuals be siblings or cousins?) or if one of the faces was different. On ‘same’ trials, all the composite faces in the array were 75% similar. Each family member was created from 3 base faces and 1 different face (e.g., a set of four relatives would look like this: ABCD, ABCE, ABCF, and ABCG). On ‘different’ trials, one of the composite faces was created from two entirely different faces than the rest of the ‘family.’ There were 20 trials per condition; half of the trials were male ‘families’ and the other half were female ‘families.’ Participants pressed either ‘z’ or ‘/’ on their keyboard to give a response of ‘same’ or ‘different.’

Condition 1: Four composite faces were presented in an array. Participants had to decide whether all faces belonged to the same 'family' (same trials) or if one face did not belong to the 'family' (different trials). See Figure 4.21 for a sample trial.

Figure 4.21. An example of a trial from Face Task 8, Condition 1. The face on the top right does not belong.

Condition 2: Six composite faces were presented in an array. Participants had to decide whether all faces belonged to the same 'family' (same trials) or if one face did not belong to the 'family' (different trials). See Figure 4.22 for a sample trial.

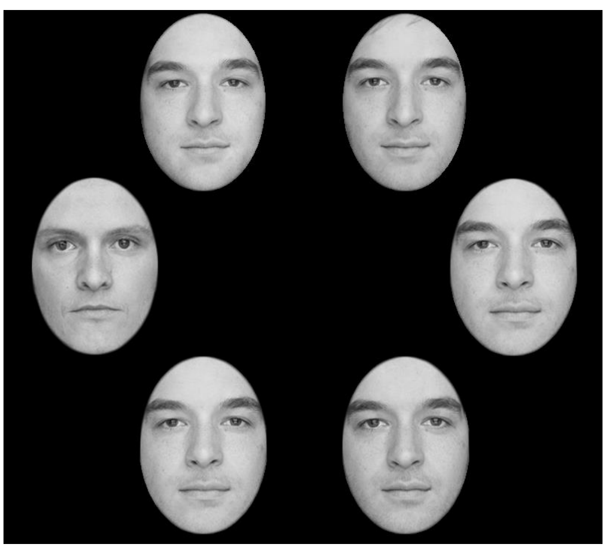

Figure 4.22. An example of a trial from Face Task 8, Condition 2. The face in the middle-left does not belong.

4.5 The Object Domain

The Attneave shapes for all object tasks were created in Matlab. The program I created to generate these shapes was based on code from Collin and Mullen's (2002) program for making Attneave shapes. All the shapes used in the object tasks had six sides (except for the shapes used in Object Task 6) and were solid black against a white background.

When creating the families of Attneave shapes, the input parameter FamilyRes determined the degree of family resemblance. This parameter has a range of 0-1 and higher values produce shapes that are more similar to each other. Values of .60 to .99 produce shapes that are subjectively similar (see Collin & Mullen, 2002 for an in-depth explanation).

4.5.1 Strict Identity Tasks in the Object Domain

Object Task 1: Same/Different Object Identity Judgment Tasks

In this task, participants had to decide if two shapes presented side by side were identical or different. As in Face Task 1, the second object was scaled down to prevent direct perceptual matching; the object on the right was 67% the size of the object on the left. There were 20 trials per condition. Participants pressed either 'z' or '/' on their keyboard to respond 'same' or 'different.'

Condition 1: On same trials, the same object appeared on the left and right of the screen. On different trials, two unrelated objects were presented (see Figure 4.23).

Figure 4.23. An example of a 'different' trial from Object Task 1, Condition 1.

Condition 2: In this condition, it was more difficult to discriminate between the two objects. As in Condition 1, on same trials, the same object appeared on the left and right of the screen. On different trials, two related but not identical objects were used (see Figure 4.24). The *FamilyRes* parameter was set to .75.

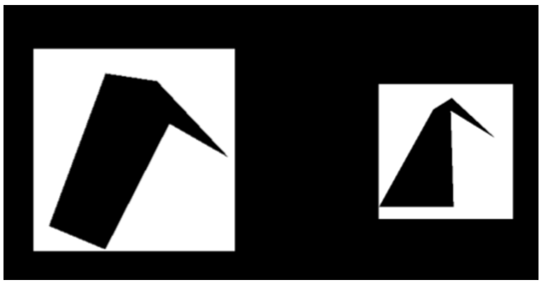

Figure 4.24. An example of a 'different' trial from Object Task 1, Condition 2.

Object Task 2: Visual Search Object Identity Task

In this task, participants were required to conduct a visual search to determine if all the objects in the array were the same or if there was one object that was different. Participants pressed either 'z' or '/' on their keyboard to respond 'same' or 'different.' Each condition consisted of 20 trials; there were 10 same trials and 10 different trials. Condition 1 and Condition 3 were tested together, and Condition 2 and Condition 4 were tested together.

Condition 1: Objects were presented in an array of four. On same trials, four identical objects were presented. On different trials, three identical objects and one unrelated object was presented (see Figure 4.25).

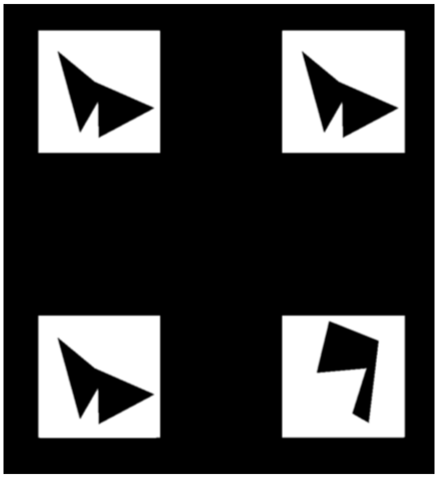

Figure 4.25. An example of a ‘different’ trial from Object Task 2, Condition 1.

Condition 2: As in Condition 1, objects were presented in an array of four. On same trials, four identical objects were presented. However, on different trials, three identical objects and one related, but not identical, object was presented (see Figure 4.26). The *FamilyRes* parameter was set to .75.

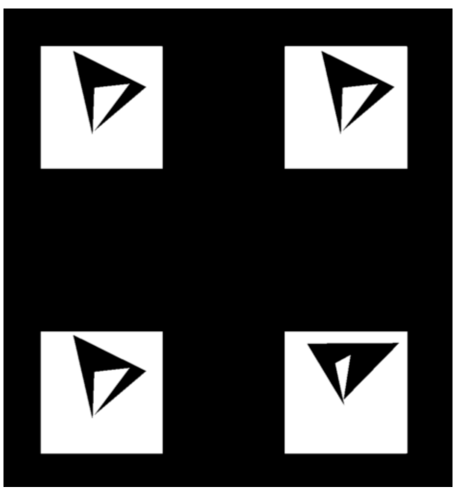

Figure 4.26. An example of a ‘different’ trial from Object Task 2, Condition 2.

Condition 3: Objects were presented in an array of six. On same trials, six identical objects were presented. On different trials, five identical objects and one unrelated object were presented (see Figure 4.27).

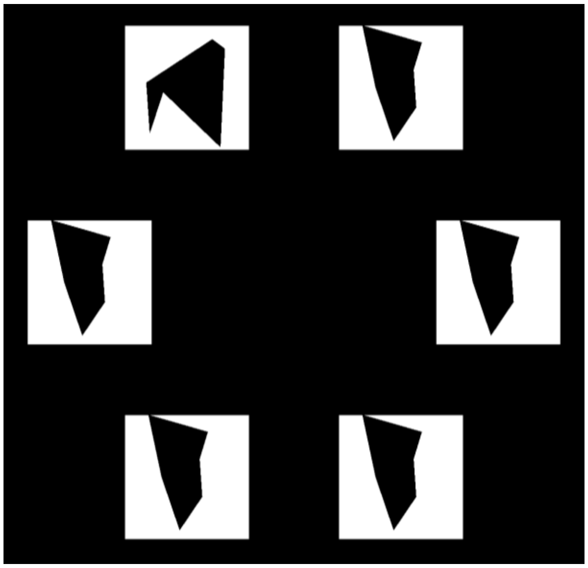

Figure 4.27. An example of a ‘different’ trial from Object Task 2, Condition 3.

Condition 4: As in Condition 3, objects were presented in an array of six. On same trials, six identical objects were presented. On different trials, five identical objects and one related object was presented (see Figure 4.28). As in Condition 2, the *FamilyRes* parameter was set to .75.

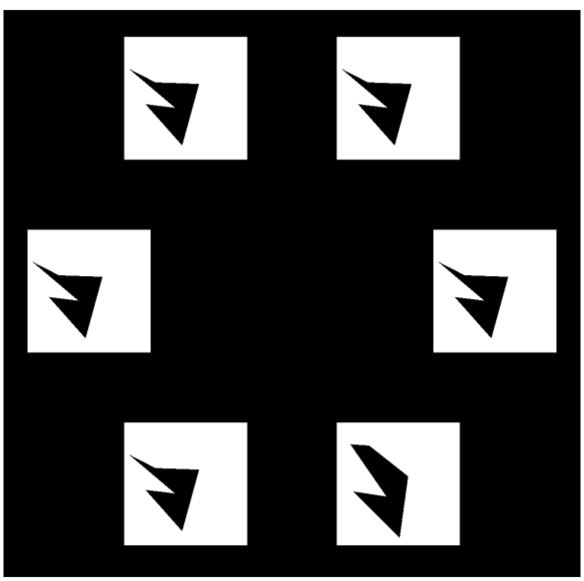

Figure 4.28. An example of a ‘different’ trial from Object Task 2, Condition 4.

Object Task 3: Forced Choice Object Identity task

In this task a sample object was presented above two other objects. One of the object choices, the target, was a match for the sample object except it was rotated 45° clockwise or counterclockwise. The other object was a different, unrelated object. Participants had to determine which of the two objects, 'left' or 'right,' matched the sample object. There were 20 trials. Participants pressed either 'z' or '/' on their keyboard to respond 'left' or 'right.' Every trial consisted of one sample object, one target that was rotated 45°, and one different, unrelated object. See Figure 4.29 for an example.

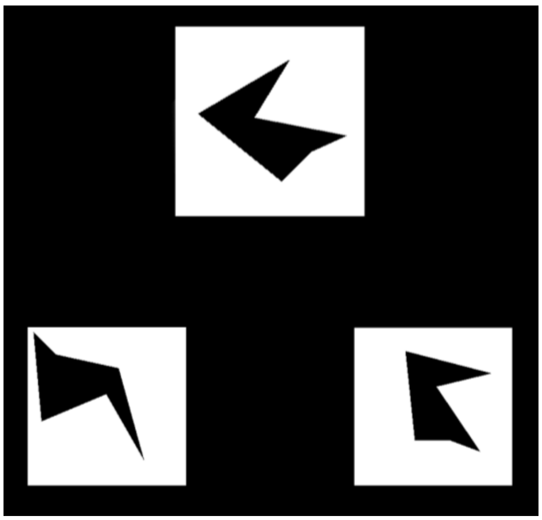

Figure 4.29. An example of a trial from Object Task 3. The object on the right is a match for the sample.

4.5.2 Attribute Judgment Tasks in the Object Domain

Object Task 4: Width Judgment

In this task, two objects were presented side by side and participants had to decide which version of the object was wider. The two objects were not aligned in order to prevent perceptual matching. There were 20 trials in each condition. Participants pressed either 'z' or '/' on their keyboard to give a response of 'left' or 'right.' Every trial consisted of one unique object and a manipulated version of this object.

Condition 1: Participants had to decide which object was wider; the wider object was manipulated to be 20% wider than the original. See Figure 4.30 for an example.

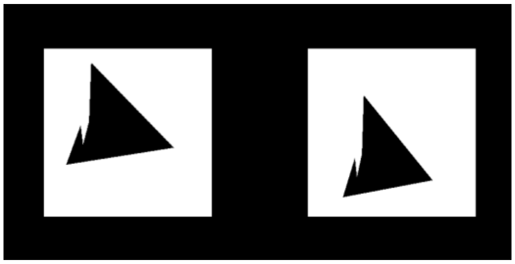

Figure 4.30. An example of a trial from Object Task 4, Condition 1. The object on the left is wider.

Condition 2: Participants had to decide which object was wider; the wider object was manipulated to be 12% wider. See Figure 4.31 for an example.

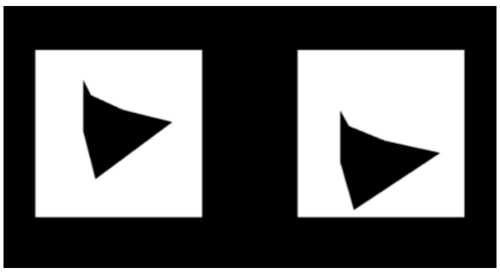

Figure 4.31. An example of a trial from Object Task 4, Condition 2. The object on the right is wider.

Object Task 5: Height Judgment

In this task, two objects were presented side by side and participants had to decide which version of the object was taller. The two objects were not aligned in order to prevent perceptual matching. There were 20 trials in each condition. Participants pressed either 'z' or '/' on their keyboard to give a response of 'left' or 'right.' Every trial consisted of one unique object and a manipulated version of this object.

Condition 1: Participants had to decide which object was taller; the taller object was manipulated to be 20% taller than the original. See Figure 4.32 for an example.

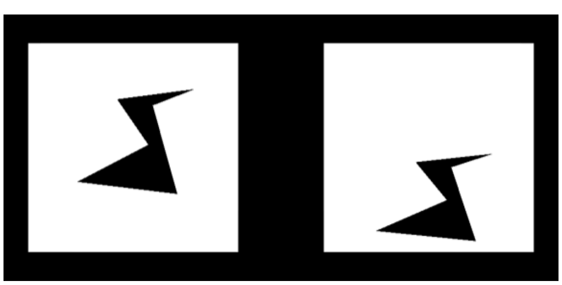

Figure 4.32. An example of a trial from Object Task 5, Condition 1. The object on the left is taller.

Condition 2: Participants had to decide which object was taller; the taller object was manipulated to be 12% taller. See Figure 4.33 for an example.

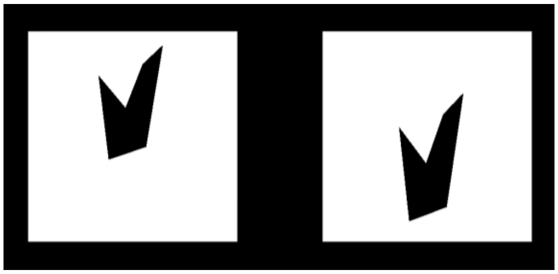

Figure 4.33. An example of a trial from Object Task 5, Condition 2. The object on the right is taller.

Object Task 6: Symmetry Judgment

In this task, participants had to decide which object was more symmetrical. There were 20 trials in each condition. Participants pressed either ‘z’ or ‘/’ on their keyboard to respond ‘left’ or ‘right.’

The symmetrical object was created by taking half of a unique Attneave shape and aligning that half with its mirror image. Due to the method in which these objects were created, the number of sides varied between objects. Every trial consisted of one unique, symmetrical object and a manipulated version of that object. The symmetrical object was perfectly symmetrical and the manipulated version of that object was skewed.

Condition 1: Participants had to decide which object was more symmetrical; the manipulated object was skewed 10° horizontally and 10° vertically. See Figure 4.34 for an example.

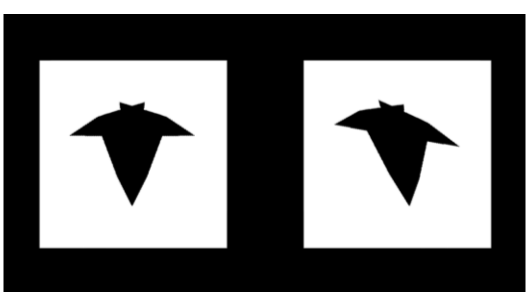

Figure 4.34. An example of a trial from Object Task 6, Condition 1. The object on the left is more symmetrical.

Condition 2: Participants had to decide which object was more symmetrical; the manipulated object was skewed either 10° horizontally or 10° vertically. See Figure 4.35 for an example.

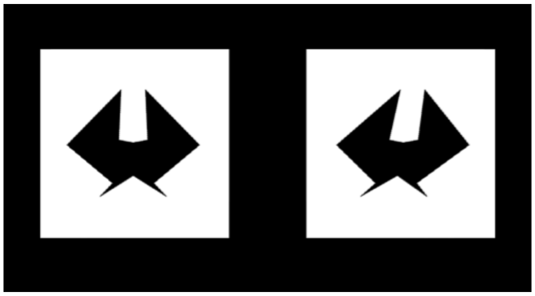

Figure 4.35. An example of a trial from Object Task 6, Condition 2. The object on the left is more symmetrical.

Condition 3: Participants had to decide which object was more symmetrical; the manipulated object was skewed either 5° horizontally or 5° vertically. See Figure 4.36 for an example.

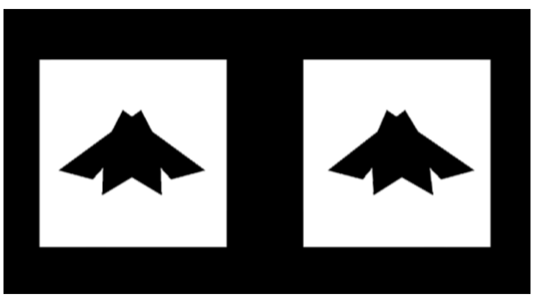

Figure 4.36. An example of a trial from Object Task 6, Condition 3. The object on the left is more symmetrical.

4.5.3 Family Resemblance Tasks in the Object Domain

Object Task 7: Forced Choice Family Member

In this task, a sample object was presented above two other objects. Participants had to decide which of the two objects most resembled the sample object. There were 20 trials in each condition. Participants pressed either ‘z’ or ‘/’ on their keyboard to respond ‘left’ or ‘right.’

Condition 1: Every trial consisted of a sample object, an object that belonged to the same ‘family’ as the sample, and an unrelated object (see Figure 4.37). The *FamilyRes* parameter was set to .85.

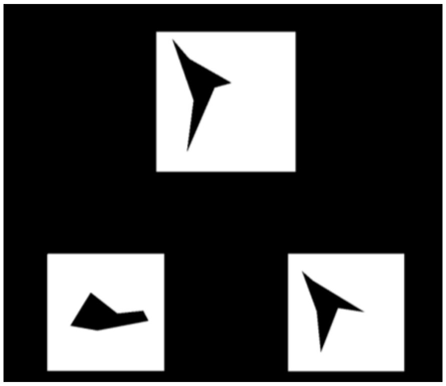

Figure 4.37. An example of a trial from Object Task 7, Condition 1. The object on the right is a closer match for the sample.

Condition 2: Every trial consisted of a sample object and two objects that belonged to the same 'family' as the sample but differed in how similar they were to the sample (see Figure 4.38). The *FamilyRes* parameter was set to .85 for the object that was most similar to the sample and to .62 for the object that was least similar to the sample.

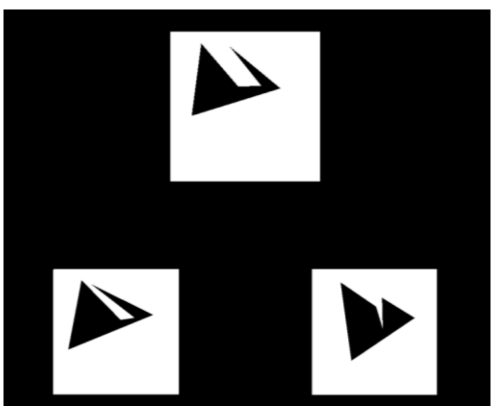

Figure 4.38. An example of a trial from Object Task 7, Condition 2. The object on the left is a closer match for the sample.

Condition 3: In Condition 3, every trial consisted of a sample object, an object that belonged to the same 'family' as the sample, and an unrelated object (see Figure 4.39). The *FamilyRes* parameter was set to .75.

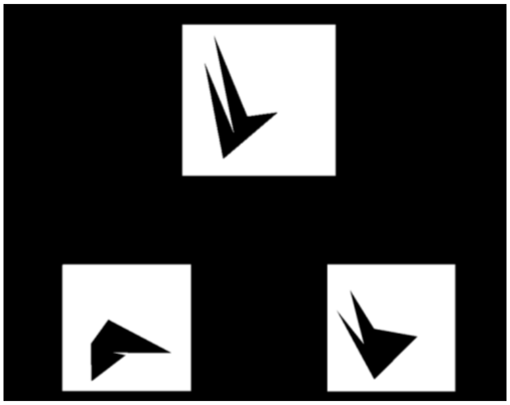

Figure 4.39. An example of a trial from Object Task 7, Condition 3. The object on the right is a closer match for the sample.

Condition 4: In Condition 4, as in Condition 2, every trial consisted of a sample object and two objects that belonged to the same 'family' as the sample but differed in how similar they were to the sample (see Figure 4.40). The *FamilyRes* parameter was set to .75 for the object that was most similar to the sample and to .62 for the object that was least similar to the sample.

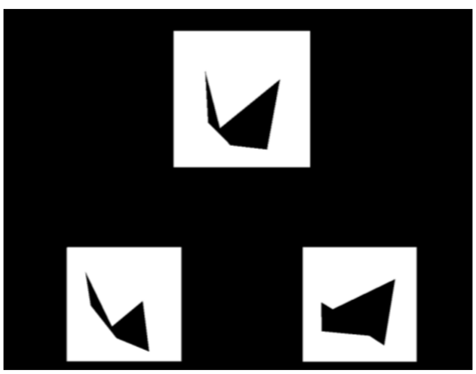

Figure 4.40. An example of a trial from Object Task 7, Condition 4. The object on the left is a closer match for the sample.

Object Task 8: Visual Search Family Member

In this task, participants were presented with an array of objects and had to decide whether all of the objects belonged to the same 'family' or if one of the objects was different from the others. Object 'families' had a *FamilyRes* parameter set to .85. On same trials, all the objects were similar. On different trials, all objects except one were similar and the different object was unrelated to the others in the array. There were 20 trials in each condition and participants pressed either 'z' or '/' on their keyboard to give a response of 'same' or 'different.'

Condition 1: Participants were shown an array of four objects and had to determine whether all the objects belonged to the same family or if one object did not belong. See Figure 4.41 for an example of a 'different' trial.

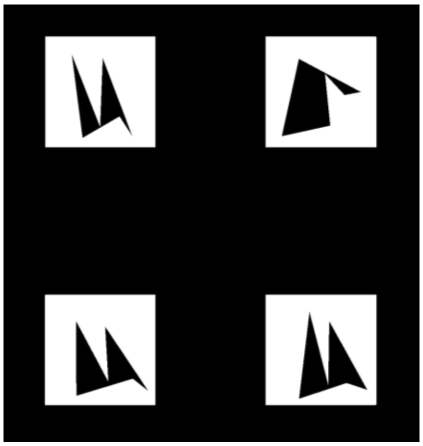

Figure 4.41. An example of a trial from Object Task 8, Condition 1. The object on the top right does not belong.

Condition 2: Participants were shown an array of six objects and had to determine whether all the objects belonged to the same family or if one object did not belong. See Figure 4.42 for an example of a different trial.

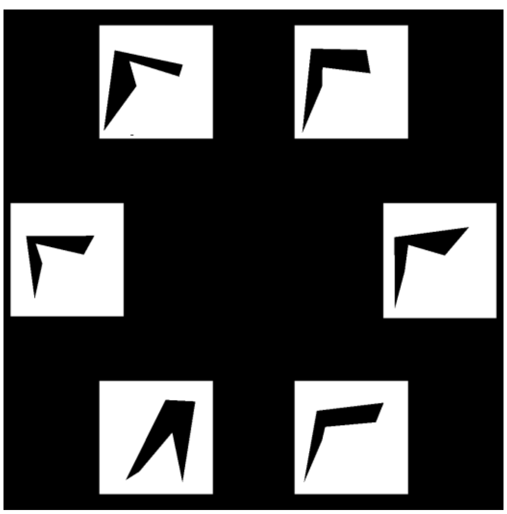

Figure 4.42. An example of a trial from Object Task 8, Condition 2. The object on the bottom left does not belong.

Chapter 5: Results

Inclusion Criteria

Careful analyses of accuracy rates at both the level of the task and the level of individual young adult (YA) and older adult (OA) participants were conducted to determine whether any tasks or any individual's accuracy rates precluded inclusion in the final data set. As mentioned in the Method section and as detailed below, application of accuracy inclusion criteria resulted in a final data set based on data from 110 adults.

As a first step, I examined the distribution of accuracy rates for each of the 16 tasks (i.e., 8 per domain) for the 140 participants who completed all the tasks to verify that the tasks were associated with mean levels of accuracy greater than 80%. Examination of the means (across all participants) revealed that accuracy rates were very reasonable for all of the object tasks (mean accuracy levels ranged from 84% to 95%) and somewhat lower for the face tasks (mean accuracy levels ranged from 80% to 91%). Notably, only one task, Face Task 5 (Femininity Judgment) hovered at 80%. Unfortunately, this task was associated with 20 participants (11 YAs and 9 OAs) with accuracy levels ranging from 40% to 64% and the accuracy levels of 14 of these 20 participants actually fell below 60%. This means that 10% of the sample could not perform the task (i.e., their accuracy shows chance performance) and an additional 5% struggled to perform the task accurately suggesting that task difficulty was manipulated too strongly for the current purposes. Therefore, I decided that Task 5 (Femininity Judgment) from the face battery should not be included in the final set of face tasks, and (for the purposes of symmetry) I did not include Task 5 (Object Width Judgment) from the object battery in the final data set.

After this first step, it was possible to apply the accuracy criterion (a minimum of 65% accuracy per task) to the 140 remaining participants to determine which of these participants' RTs could be included. Although it is painful to lose data, it is not possible to interpret reaction time data when accuracy rates are not significantly above chance. Indeed, the loss was steep, because applying this criterion resulted in 30 fewer participants (i.e., 10 YAs from WU, 7 YAs from MTurk , and 13 OAs could not be included). Combining the two inclusion criteria (complete all tasks with 65% accuracy or greater on the 14 tasks remaining after elimination of Task 5 in each battery) reveals that the two age groups were affected similarly. To make this comparison, it is important to begin with the pool of 150 adults who were administered the two batteries, and to note that110 adults met the inclusion criteria. Specifically, 74 YAs of the 98 YAs (i.e., about 75%) were included in the final data set and 36 OAs of the 52 OAs (i.e., about 70%) were included in the final data set.

All further analyses were conducted using the final data set, which consisted of the data from 110 participants performing 14 tasks (7 per battery). Mean accuracy rates for the 14 processing speed tasks as a function of stimulus domain and as a function of age group are provided in Table 5.1. Notably, failure to respond within 15000 ms, was recorded as an error. Participants were advised that failing to respond within 15 s would count as an error and the software would advance to the next trial. Trials in this category were extremely rare in both age groups: Young Adult M = 0.058% (SD = 0.063%) of all trials and Older Adult M = 0.085% (SD = 0.091%). Additionally, very short RT trials (<250 ms) occasionally occurred but these trials, which were omitted from all analyses (i.e., they were not counted as errors), were relatively rare in both age groups: Young Adult M = 0.52% (SD = 0.80%) of all trials and Older Adult M = 0.42% (SD = 0.62%) of all trials. Mean accuracy rates as a function of the two YA groups are provided in the Appendix (along with an RT analysis showing the YA groups were very similar and therefore were combined in the final data set).

Table 5.1 Mean (*M*) Accuracy Rates (in percentage) and Standard Deviations (SD) for the Face and Object Task Batteries as a function of Age

	TASKS						
	TASK 1	TASK 2	TASK 3	TASK 4	TASK 6	TASK 7	TASK 8
GROUP	FACE BATTERY						
YNG (*M*)	84.7	85.2	93.8	88.3	91.7	84.1	87.5
YNG (*SD*)	7.7	7.5	5.8	8.6	6.6	6.9	6.7
OLD(*M*)	82.3	82.3	89.7	84.2	92	85.4	85.9
OLD(*SD*)	8.6	8.6	8.1	9.7	7.2	6.8	7.4
	OBJECT BATTERY						
YNG (*M*)	91.7	94.1	97.1	95.3	95	92.9	86.9
YNG (*SD*)	5.9	5.1	5.3	4.9	3.8	3.7	7.1
OLD(*M*)	91.6	96.5	96.9	94.6	96.3	94.7	84.3
OLD(*SD*)	5.3	3.3	5	6.5	4.3	3.2	7.9

Brinley Plot Analysis of Accuracy Rates

To test for differential age-related slowing between the face and object domain in terms of accuracy rates, group means for all 14 tasks (7 tasks per domain) were calculated based on the mean of the condition means for each participant. The older adult group's mean accuracy rate for each task was then plotted as a function of younger adult group's corresponding mean accuracy rate in a Brinley plot (see Figure 5.1).

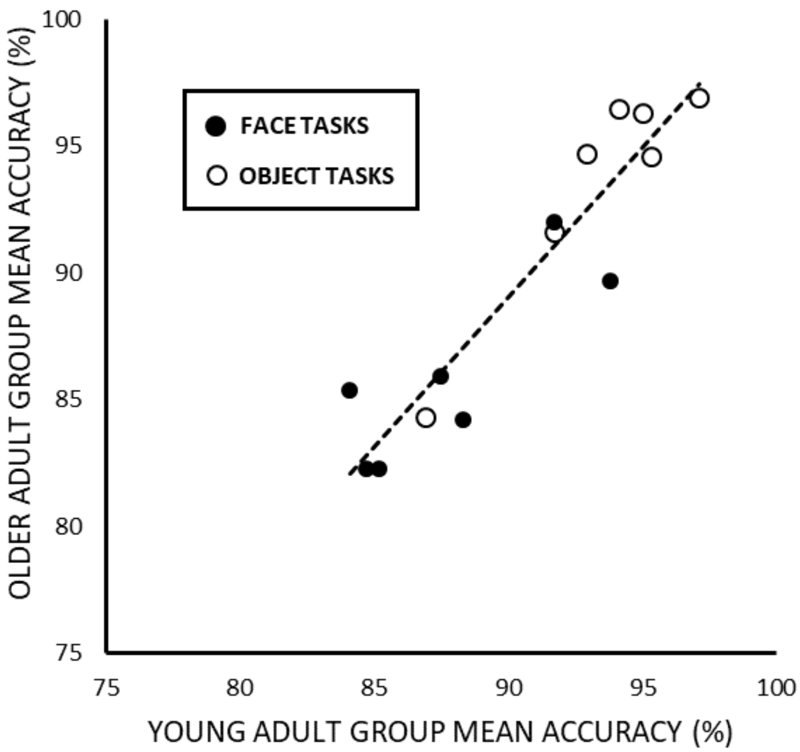

Figure 5.1. Older adult group's mean rate of accuracy (percentage correct) on face and object processing tasks (filled and open circles, respectively) plotted as a function of the corresponding mean rate of accuracy from the young adult group. Analyses (see text) revealed that these data were best fit by a single linear function (represented here by the dotted line).

Multiple linear regression analyses were conducted comparing a full model that distinguished between the two stimulus domains (i.e., face vs. object) with a reduced model that did not incorporate this distinction. Analysis based on the full model of the relation between older adult accuracy rates and young adult accuracy rates failed to reveal significant differences between either the intercepts, $t(12) = 1.07$, $p = .216$, or the slopes, $t(12) = 1.10$, $p = .194$, associated with the two stimulus domains. Fitting the reduced model (a simple linear function) to the data revealed that older adults' accuracy rates were accurately predicted by young adults' accuracy rates regardless of domain, $R^2 = .870$, $F(1, 12) = 80.64$, $p < .001$.

Reaction Times

Data reduction of the RTs consisted of obtaining the median RT for each of the 20 conditions for each stimulus battery for each of the 110 participants in the final data set. The median RT was chosen over the mean RT because the RTs of OAs in several task conditions included numerous RTs > 8000 *ms*, which would mean that OAs' measure of central tendency would be more affected by very long RTs (when using the mean) than YAs' corresponding RTs and could also influence potential domain (i.e., faces vs. objects) differences in OAs. The percentage of trials in which correct RTs fell into this category for YAs was $M = 0.33$ ($SD = 0.66$) and for OAs the percentage was $M = 1.41$ ($SD = 1.45$). For the Condition-level analyses, the data were reduced by calculating the median RT from each participant for each condition in each task. For the Task-level analyses, the RT data were then further reduced by taking the mean of the medians calculated separately for each condition in each task.

Notably, although every experimental condition had a corresponding counterpart in the other domain, the face processing tasks in this study were more difficult compared to the object processing tasks, as indexed by overall mean RTs in each domain. That is, the overall mean RT for tasks in the face domain (collapsed across age) was 2115 *ms* and it was 1437 *ms* for tasks in the object domain. The face processing tasks also had a larger range of difficulty. As can be seen in Table 5.2, the young adult group's mean response times ranged from 1064 *ms* to 2361 *ms* on face processing tasks and from 906 *ms* to 1587 *ms* on object processing tasks. In contrast, the older adult group's mean response times ranged from 1494 *ms* to 3723 *ms* on face processing tasks and from 1194 *ms* to 2341 *ms* on object processing tasks. From the current perspective, what is most important to note is that the range of RTs for the young adult group's face processing tasks successfully overlaps with the RTs for the young adult group's object processing tasks (that is, the range of task difficulty in the object domain fell almost entirely within the range of task difficulty in the face domain, which extended well beyond the range of the object tasks).

Table 5.2 Group RT Means(*M*) and Standard Deviations (*SD*) in *ms* for Each Age Group as a function of Task and Stimulus Domain of the Task Battery

	TASKS						
	T1	T2	T3	T4	T6	T7	T8
GROUP	FACE BATTERY						
YNG (*M*)	1478	2361	1764	1328	1064	1630	2291
YNG (*SD*)	444	740	458	413	286	485	806
OLD (*M*)	2181	3723	2443	1881	1494	2585	3393
OLD (*SD*)	963	1023	669	584	385	791	1152
	OBJECT BATTERY						
YNG (*M*)	1067	1323	1146	1057	906	1120	1587
YNG (*SD*)	267	390	302	324	220	301	549
OLD (*M*)	1498	1951	1749	1432	1194	1742	2341
OLD (*SD*)	379	602	469	524	227	415	877

Note: T1 = Task 1, T2 = Task 2, etc.

Inter-Task Correlations

Inter-task correlations of response times among all 14 tasks from the two batteries are shown separately for the young and older groups in Tables 5.3 and 5.4, respectively. Notably, the correlations among the tasks on each battery had ranges that were similar for the two age groups especially for the face tasks, which ranged from .382 to .791 in younger adults (*M* = .584) and from .326 to .822 in older adults (*M* = 0.553). For object tasks, *r* values ranged from .471 to .816 in younger adults (*M* = .641) but from .161 to .807 in older adults (*M* = .523). One pattern revealed by visual inspection of the correlations found in these tables is that for both age groups, the same-domain correlations included the strongest correlations coefficients, but were nonetheless more similar to the cross-domain correlations than different; a pattern that is inconsistent with two separate domain-specific abilities.

Table 5.3 Inter-task Correlations of Response Times among the Young Adults for each Task Battery (same-domain correltions) and for the Two Task Batteries (cross-domain correlations).

FACE BATTERY

	Face T1	*Face T2*	*Face T3*	*Face T4*	*Face T6*	*Face T7*
Face T2	.739					
Face T3	.737	.713				
Face T4	.529	.440	.538			
Face T6	.481	.515	.585	.382		
Face T7	.625	.655	.565	.519	.491	
Face T8	.767	.791	.629	.471	.491	.595

OBJECT BATTERY

	Object T1	*Object T2*	*Object T3*	*Object T4*	*Object T6*	*Object T7*
Object T2	.792					
Object T3	.471	.730				
Object T4	.535	.692	.545			
Object T6	.672	.720	.504	.736		
Object T7	.719	.816	.663	.617	.705	
Object T8	.635	.740	.503	.496	.525	.656

TWO BATTERIES

	Face T1	*Face T2*	*Face T3*	*Face T4*	*Face T6*	*Face T7*	*Face T8*
Object T1	.454	.564	.446	.330	.538	.526	.484
Object T2	.674	.641	.623	.490	.648	.577	.624
Object T3	.662	.614	.616	.384	.652	.502	.676
Object T4	.555	.447	.635	.443	.716	.446	.438
Object T6	.476	.496	.489	.384	.749	.553	.386
Object T7	.536	.655	.576	.493	.694	.627	.535
Object T8	.623	.615	.582	.434	.479	.543	.615

Note: All correlations in all three sections of this table were statistically significant.

Table 5.4 Inter-task Correlations of Response TImes among the Older Adults for each Task Battery (same-domain correltions) and for the Two Task Batteries (cross-domain correlations).

FACE BATTERY

	Face T1	*Face T2*	*Face T3*	*Face T4*	*Face T6*	*Face T7*
Face T2	.731					
Face T3	.646	.703				
Face T4	.457	.354	.548			
Face T6	.515	.428	.378	.326		
Face T7	.583	.690	.706	.472	.428	
Face T8	.692	.822	.635	***.257***	.518	.712

OBJECT BATTERY

	Object T1	*Object T2*	*Object T3*	*Object T4*	*Object T6*	*Object T7*
Object T2	.807					
Object T3	.623	.746				
Object T4	.597	.511	.365			
Object T6	.410	.561	.522	***.161***		
Object T7	.394	.620	.535	.383	***.265***	
Object T8	.724	.698	.479	.797	***.258***	.518

TWO BATTERIES

	Face T1	*Face T2*	*Face T3*	*Face T4*	*Face T6*	*Face T7*	*Face T8*
Object T1	.601	.579	.631	***.206***	***.262***	.502	.530
Object T2	.663	.584	.724	.352	.569	.541	.656
Object T3	.369	.372	.589	.329	.580	.589	.552
Object T4	.442	.380	.511	***.227***	***.166***	.364	***.261***
Object T6	.361	.515	.626	.370	.480	.560	.481
Object T7	.598	.528	.560	.415	.589	.620	.649
Object T8	.562	.569	.623	***.206***	***.204***	.497	.491

Note: All correlations in all three sections of this table were statistically significant except for those shown in bold italics.

Principal Components Analysis

The results of a principal components analysis (PCA) conducted on the RTs in the final data set were consistent with the impression based on the intercorrelations among RTs shown in Tables 5.3 and 5.4. The PCA found only one component with an eigenvalue greater than 1.0, and all tasks (see Table 5.5) loaded strongly on this component (eigenvalue = 9.69), which accounted for 69.2% of the variance. Forcing the analysis to include two principal components does reveal a second bipolar principal component (eigenvalue = .791) on which some of the tasks loaded very weakly: 4 of the 14 tasks (Face Task 4 = .353, Object Task 1 = -.317, Object Task 4 = -.478, and Object Task 7 = -.355). Including this second component accounted for an additional 5.6% of the variance. As can be seen in Table 5.5, 8 of the remaining 10 task loadings on this second component were negligible (i.e., loadings <.200) and the final 2 task loadings were extremely weak (i.e., loadings > .200 but < .250). Thus, the loadings on the forced second component provide, at best, a small sliver of support for the role of stimulus domain.

Table 5.5

Component Loadings for Each Task

Tasks	PC 1	PC 2
Face Task 1	0.829	0.141
Face Task 2	0.882	0.180
Face Task 3	0.875	0.073
Face Task 4	0.693	0.353
Face Task 5	0.795	0.099
Face Task 6	0.859	0.218
Face Task 7	0.842	0.245
Object Task 1	0.841	-0.317
Object Task 2	0.918	-0.180
Object Task 3	0.852	0.015
Object Task 4	0.736	-0.478
Object Task 5	0.795	-0.040
Object Task 6	0.883	0.039
Object Task 7	0.816	-0.355

Brinley Plot Analyses of RTs

To test for differential age-related slowing between the face and object domain at the task level, group means for all 14 tasks (7 tasks per battery) were calculated based on the mean of the condition medians for each participant. Older adult group's mean RT for each task was plotted as a function of younger adult group's corresponding mean RT in a Brinley plot (see Figure 5.2).

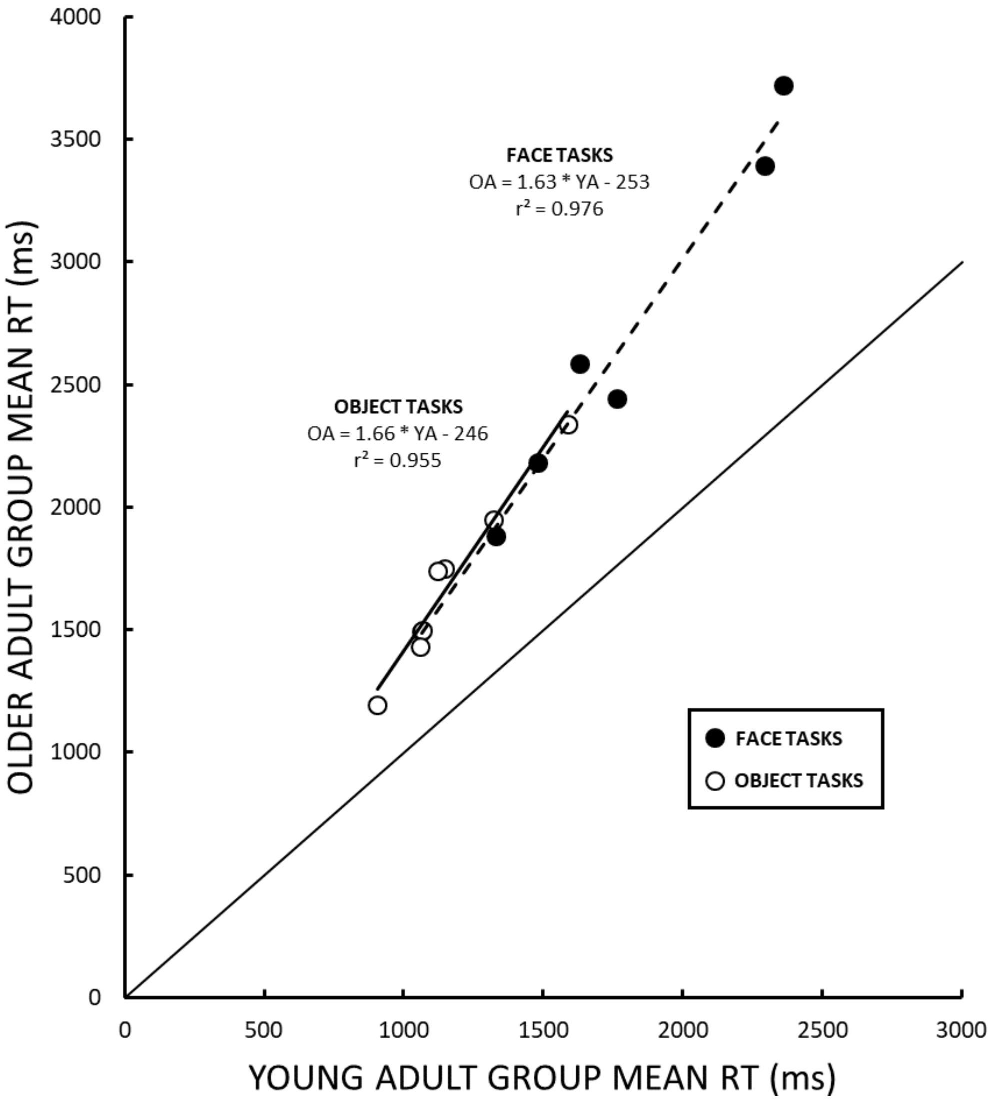

Figure 5.2. Older adult group's mean RTs on face and object processing tasks (filled and open circles, respectively) plotted as a function of the corresponding mean RTs from the young adult group. If the RTs of the two age groups on a given task were equal, the data point would fall on the diagonal line. Linear regression equations are provided for each domain separately; the dashed line represents the fit to the face tasks and the solid line represents the fit to the object tasks. Analyses (see text) revealed that these data were best fit by a single linear function.

Multiple linear regression analyses were conducted comparing a full model that distinguished between the two stimulus domains (i.e., face vs. object) with a reduced model that did not incorporate this distinction. Analysis based on the full model of the relation between older adult RTs and young adult RTs failed to reveal significant differences between either the intercepts ($t < 1.0$, $p = .982$) or the slopes ($t < 1.0$, $p = .909$) associated with the two stimulus domains. Fitting the reduced model (a simple linear function) to the data revealed that older adults' RTs were accurately predicted by young adults' RTs regardless of domain, $R^2 = .981$, F $(1, 12) = 627.57$, $p < .001$. It should be noted that the slope of the reduced model, $\beta = 1.61$, was significantly greater than 1.0, $t(12) = 9.49$, $p < .001$, indicating that the older adults were approximately 60% slower than young adults at processing both face and object stimuli.

To test for age-related differential slowing at the condition level, I used the mean of the median RTs for each condition (i.e., 18 conditions per domain) for each age group (see Table 5.6 for the means and standard deviations for all conditions for each age group). The older adult group's mean RTs for each condition were then plotted as a function of the younger adult group's mean RTs in the same condition in a Brinley plot (see Figure 5.3).

Table 5.6 Group RT Means(*M*) and Standard Deviations (*SD*) in *ms by* Age Group as a Function of Task Condition and the Stimulus Domain of each Divided Task Battery

	FACE BATTERY (Tasks 1, 2, 3, 4)								
GROUP	T1C1	T1C2	T2C1	T2C2	T2C3	T2C4	T3C1	T4C1	T4C2
YNG (*M*)	1411	1544	2035	2223	2468	2720	1764	1190	1466
YNG (*SD*)	415	519	652	824	817	977	458	296	583
OLD (*M*)	1998	2364	3077	3538	3915	4362	2443	1694	2067
OLD (*SD*)	801	1158	1005	1215	1048	1312	669	450	789

	FACE BATTERY (Tasks 6, 7, 8)								
	T6C1	T6C2	T6C3	T7C1	T7C2	T7C3	T7C4	T8C1	T8C2
YNG (*M*)	987	1065	1142	1482	1570	1686	1783	2056	2528
YNG (*SD*)	262	306	313	380	477	568	700	738	903
OLD (*M*)	1355	1439	1688	2202	2538	2708	2892	3122	3664
OLD (*SD*)	382	367	565	581	818	1069	958	1173	1241

	OBJECT BATTERY (Tasks 1, 2, 3, 4)								
	T1C1	T1C2	T2C1	T2C2	T2C3	T2C4	T3C1	T4C1	T4C2
YNG (*M*)	1013	1121	1024	1451	1135	1681	1146	1012	1101
YNG (*SD*)	256	290	265	475	383	581	302	296	365
OLD (*M*)	1389	1606	1474	2127	1709	2495	1749	1374	1490
OLD (*SD*)	321	457	440	736	555	901	469	549	515

	OBJECT BATTERY (Tasks 6, 7, 8)								
	T6C1	T6C2	T6C3	T7C1	T7C2	T7C3	T7C4	T8C1	T8C2
YNG (*M*)	824	854	1039	976	1094	1169	1239	1466	1707
YNG (*SD*)	184	195	309	228	273	333	428	533	603
OLD (*M*)	1059	1132	1391	1480	1595	1921	1973	2113	2569
OLD (*SD*)	153	200	365	380	336	505	574	704	1083

Note: T1C1 = Task 1, Condition 1; T1C2 = Task 1, Condition 2; T2C1 = Task2, Condition 1, etc.

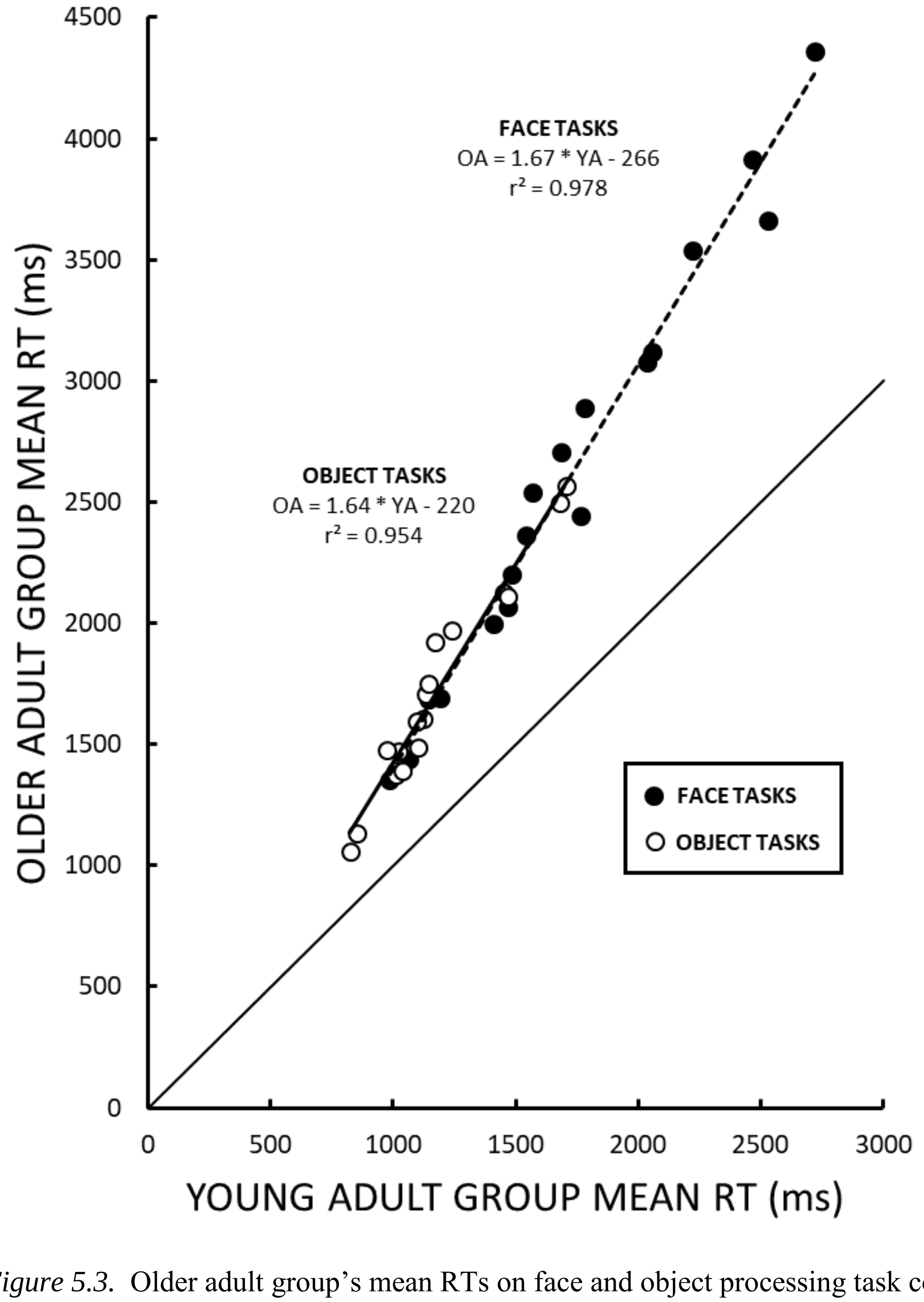

Figure 5.3. Older adult group's mean RTs on face and object processing task conditions (filled and open circles, respectively) plotted as a function of the corresponding mean RTs for the young adult group. If the RTs of the two age groups on a given task were equal, the data point would fall on the diagonal line. Linear regression equations and fit statistics are provided for each domain separately; the dotted line represents the fit to the face tasks and the solid line represents the fit to the object tasks. Analyses (see text) revealed that these data were best fit by a single linear function.

The results of multiple linear regression analyses at the condition level were consistent with those observed at the task level. Analysis based on the full model of the relation between older adult RTs and young adult RTs again failed to reveal significant differences in either the intercepts ($t < 1.0$, $p = .784$) or the slopes ($t < 1.0$, $p = .858$) associated with the two stimulus domains. As with the analysis of the RTs of the tasks, for the conditions, the slope of the reduced model, $\beta = 1.65$, was significantly greater than 1.0, $t\,(34)= 16.81$, $p < .001$, indicating that at the condition level, the older adults were approximately 65% slower than younger adults at processing both face and object stimuli. Moreover, older adults' RTs again were accurately predicted by young adults' RTs regardless of domain, $R^2 = .982$, $F(1, 34) = 1815.92$, $p < .001$.

Chapter 6: Discussion

Although early models of age-related slowing claimed slowing was general across domains (Cerella et al., 1980; Salthouse, 1973), the finding of differential rates of slowing between lexical processing and visuospatial processing (Lima et al., 1991; Lawrence et al., 1998) has spurred a series of investigations with the aim of uncovering how many dissociations exist (for a full review, see Verhaeghen, 2014). Different classes of stimuli or different types of cognitive processing may show differential slowing. However, it remains unknown just how specific domain-specific slowing is. That is, neural specialization dedicated to processing a special class of stimuli within a domain could lead to dissociations, and this was the motivation for the current study.

With a large set of perceptual processing tasks using both face and object stimuli, I investigated whether the rate of age-related slowing is general within the domain of visuospatial processing or if slowing is more specific and proceeds at a different rate for face processing compared to object processing. In the current study, two rates of age-related slowing seemed especially likely given that there exist specialized neural pathways for processing faces and these qualitative differences between face and object processing are evident across the lifespan (Hildebrandt et al., 2011; Boutet & Faubert, 2006).

Contrary to the expectation that separate processing pathways for faces and objects would lead to two different rates of decline, the findings unequivocally show that the rates of slowing in the face and object domains are indistinguishable. I conducted Brinley analyses which, surprisingly, revealed only one slowing function. A single line fit the plotted data, which indicated that older adults' performance could be predicted by young adults' performance, irrespective of domain (i.e., regardless of whether the tasks involve face processing or object processing), using a single slowing equation to make the prediction.

In addition to null hypothesis statistical tests, I also conducted Bayesian hypothesis testing to determine whether the data supported the null (Rey-Mermet & Gade, 2018). In traditional statistical methods, probability values reflect the strength of the evidence against the null hypothesis. A failure to reject the null hypothesis, however, does not constitute support in favor of that hypothesis. The advantage of using Bayesian statistical analysis in conjunction with standard hypothesis testing is that it enables us to assess the strength of the evidence for the null as well as for the alternative hypothesis (Kass & Raftery, 1995). I was interested in the effect of stimulus-domain (i.e., face vs. object processing) on slowing, and so my attention focused on the interaction terms reflecting potential differences in slowing rates, which were found to not be significant. Following Raftery's (1995) classification guidelines, which designate Bayes Factors above 3 as positive evidence and above 20 as strong evidence, I found strong support for the null hypothesis of equivalent age-related slowing of both face and object processing. Taken together, the failure to reject the null combined with the very strong Bayes Factors of 36.00 and 9.59 observed at the level of conditions and tasks, respectively, constitute substantial evidence in favor of the null hypothesis that there is no differential slowing of face and object processing.

Several previous studies have focused on age-related slowing in face or object processing (e.g., Hildebrandt et al., 2013; Swearer & Kane, 1996), but few studies have taken a systematic approach comparing slowing between faces and objects in purely perceptual tasks. Prior research in younger adults has found that face processing is dissociable from measures of general cognition (e.g., recognition and perception of verbal and visuospatial information), in both accuracy and speed of processing (Hildebrandt et al., 2011; Wilhelm et al., 2010). Hildebrandt et al. conducted an extensive investigation into age-related changes in general cognition, assessed by speed tasks with symbols, numbers, and words, and face cognition. Their findings support a dissociation in speed measures between face and general cognition, which confirms previous work in younger adults by Wilhelm et al. (2010) and mirrors findings of differential slowing between the lexical and visuospatial domains (Lima, Hale, & Myerson, 1991; Hale et al., 1995; Lawrence et al., 1998).

Swearer and Kane (1996) argued for a process-specific model of age-related slowing of object processing that posits that the rate of slowing is not general within a domain but that there are dissociations between different types of processing. They found differential slowing on visuospatial processing tasks that used identical stimuli but differed in processing demands (i.e., simultaneous matching vs. delayed matching). Greater age-related slowing was observed for simultaneous matching tasks than for delayed matching tasks, consistent with a process-specific model. However, the dissociation likely reflected a difference in strategies used by older adults for perceptual processing tasks versus tasks involving a memory component, rather than a difference in central processing. For example, it was advantageous for older adults to respond more quickly during a delayed matching task because the sample stimulus was no longer visible after a delay, and participants could only rely on a fading memory trace to choose the correct match. Nonetheless, the finding of strategic differences between older and younger adults on tasks with a memory component highlights the importance of avoiding comparisons of dissimilar tasks because RT measures obtained from certain tasks (e.g., recognition) may not reflect processing speed in the same way that RTs on pure perceptual tasks do.

Hildebrandt et al. (2013) investigated age-related dissociations in face and object processing by comparing processing speed in older and younger adults in tasks using faces and houses. Speed of processing for both faces and objects, however, was assessed using recognition as well as perceptual tasks, despite the potential strategic differences on recognition and perception tasks. Moreover, unlike the current study, most of the tasks used to assess face and object processing were not matched, which could result in unintended comparisons of different cognitive processes in addition to the intended comparison of different classes of stimuli. The use of house stimuli in the object tasks, however, permitted a close match in visual complexity between faces and objects (i.e., houses are more complex visual stimuli than other objects), and the authors found no evidence of a dissociation in the rate of slowing associated with faces and complex objects, which is in line with the current findings. However, Hildebrandt et al. focused on the relations between latent factors and age, and thus their analyses addressed a fundamentally different, albeit related, issue from that considered here.

The difference between the issues addressed by Hildebrandt et al. (2013) and the current study may be described in terms of the difference between correlation and regression. In essence, their analyses asked whether face speed remained as good a predictor of object speed in older adults as it was in younger adults. The answer to this question was ‘yes,’ but although it is an important question, it is not the same question as the question addressed here, which concerned whether the same regression equation could predict older adults’ processing speed on a particular visuospatial task from younger adults’ speed on that same task, regardless of whether the task required processing object or face information. Again, the answer was ‘yes,’ but whereas the answer to the first question follows from the answer to this second question, the reverse is not true.

Consider the relation between verbal and visuospatial memory span, which are strongly enough correlated across the adult life span that many researchers assess a single general factor based on scores on both verbal and visuospatial memory tasks (Kane et al., 2004; Park et al., 2002). Despite the fact that a person's verbal span remains a good predictor of their spatial span as they get older (i.e., the correlation shows relatively little change with age), just as face processing speed remains a good predictor of object processing speed (Hildebrandt et al., 2013), visuospatial spans decline approximately twice as fast as verbal spans (i.e., the slope of the regression of visuospatial on age is about twice that of the verbal slope). Thus, although the current study and that of Hildebrandt et al. may initially appear to some to be redundant, the current study provides new and important information about the relation between age-related differences in face and object processing that complements that provided by Hildebrandt et al. Moreover, the fact that the information provided by the current study is based not only on more face and object processing tasks but also on tasks that are carefully matched (unlike those of the previous study), means that, even where the current results do correspond to those of Hildebrandt et al., as in the present finding that a single factor captures individual differences in both face and object processing, the current findings represent more than a simple replication and should greatly increase confidence in their original finding.

Although some researchers have explored slowing within the face domain, an extensive investigation specifically comparing the slowing of face and object processing was long overdue. The results of the current study were contrary to my original expectations but are consistent with a domain-specific slowing hypothesis: Qualitative differences in the processing of different classes of stimuli within the visuospatial domain (i.e., the processing of faces and objects) and neural-specificity for faces are not necessarily indicative of differential slowing. In other words, the current study provided no evidence that slowing is more than domain-specific. These findings imply that visuospatial slowing reflects age-related differences in a general mechanism specific to that domain even though face processing is in at least some other respects qualitatively distinct from other types of cognitive functions, including object processing (Hildebrandt et al., 2011; McKone, Martini, & Nakayama, 2001; Boutet & Faubert, 2006). It will be of considerable interest whether slowing in other domains (e.g., verbal processing) shows similar characteristics; that is, whether there are kinds of verbal processing that appear qualitatively distinct yet are equivalently slowed as people get older.

Clearly, the supposition that greater age-related impairments in face processing, relative to object processing, might be associated with differential slowing was not supported by the results of the current study. Reports of age-related deficits in face processing, as reflected in decreased accuracy of discrimination performance for example, are ubiquitous in the literature (Grady et al., 1995; Gao et al., 2009; Daniel & Bentin, 2010; Searcy et al., 1999; Bartlett & Fulton, 1991), but as other researchers have noted, they are separable from age-related differences in speed measures (Hildebrandt et al., 2013). Researchers examining individual differences in face cognition abilities in young adults, moreover, have found that measures of face perception and face memory performance tap different abilities than measures of face processing speed (Wilhelm et al., 2010), strongly suggesting that the observed dissociations reflect different underlying cognitive mechanisms that go beyond differences in the effects of age on neuronal function or strategy selection and efficiency. That is, if the changes responsible for the observed deficits in the accuracy of face processing also explained slowing in the face domain, one would have seen differential slowing rates for faces and objects. If, however, the mechanism responsible for slowing in the visuospatial domain operates at an early stage of visual processing, before face-specific processing occurs, then results like the present findings, in which face and object processing are slowed to similar degrees, would be expected. It is also possible that the slowing mechanism arises from the neural regions that are common to both face and object processing. It has been observed that neurons in the fusiform face area, which respond maximally to faces, and neurons in the parahippocampal place area, which show higher activation to non-face objects such as houses, are also activated to a lesser extent by objects and faces, respectively (Haxby et al., 2001). This suggests that although there are specialized pathways for processing faces, neural face processing shows considerable overlap with neural object processing, which could explain the current findings. However, more research will be needed to determine what governs the rate of processing of any class of visuospatial stimuli at any age.

There were several limitations to the current study. To begin with, data from some tasks and participants had to be excluded. Despite efforts to ensure that all tasks were simple enough to yield high accuracy rates and variability in RTs, one of the face tasks (i.e., judgments of femininity in Face Task 5) proved too difficult for a substantial number of participants and was excluded along with its counterpart from the object processing domain. Previous research on perceived masculinity and femininity of manipulated faces has shown that masculinization and feminization of face stimuli using the same methods as in this study has the intended effects (DeBruine et al., 2006; Jones et al., 2005; Perret et al., 1998; Welling et al., 2007). In previous studies, participants had to decide which face was more masculine from a pair of manipulated versions of the same face, one masculinized version and one feminized version, as in Condition 1 of Task 4 and 5 (DeBruine et al., 2006; Jones et al., 2005; Welling et al., 2007), or participants had to rank three faces (feminized, average, and masculinized) in order of increasing masculinity (Perret et al., 1998). In Condition 2 of Task 4 and 5 of the current study, participants had to choose between a manipulated face and the original face, which may have increased the difficulty of the task. It is unclear why the task was more difficult with female faces than with male faces despite that the manipulation was the same in both tasks. Notably, had all participants adopted a feature-based strategy (i.e., focusing on one feature, such as the thickness of the brows), it is unlikely that accuracy on the feminization task would have been very low; participants were likely considering the entire face when making masculinity and femininity judgments. Moreover, although for both age groups, the average accuracy across all the remaining tasks was above 85% for face processing and above 92% for object processing, not all participants could achieve at least 67% on every task and so were excluded, potentially limiting the generality of the present findings.

Another potential concern is the fact that although research in the field has validated studying cognitive aging using online experiments (Bui et al., 2015), this approach, which was used in the current study, can introduce new problems, especially when the study requires a significant time commitment, as in the present case. The MTurk platform ensures the anonymity of participants, but, because all communication must be initiated through the platform, this can make it difficult to contact participants who may have unintentionally skipped a task. Furthermore, without the lab setting or the physical presence of a researcher, participants may feel less inclined to complete every single task with the same level of care, and some participants had to be excluded from the final analyses due to incomplete or inaccurate performance. Finally, because only two age groups were compared in this study, it was impossible to determine the shape of the function describing the slowing of face processing over the lifespan. It has been shown, however, that RTs on visuospatial tasks with nonface objects increase exponentially with age (Cerella & Hale, 1994; Lawrence et al., 1998). Given that there appears to be no dissociation in the rate of slowing between the two stimulus domains (i.e., face vs. object processing), it is therefore likely that the slowing associated with face processing is also exponential in form, although this will need to be verified experimentally.

Several conclusions can be drawn from the current study. First, the present findings strongly support the view that a single mechanism governs speed of processing within the visuospatial domain, regardless of the type of stimuli. Age-related changes in the efficiency of this mechanism, in turn, would then represent the source of slowing not just in processing visually simple objects (e.g., Attneave shapes) but in processing complex visual stimuli (e.g., faces and houses) as well (e.g., Hildebrandt et al., 2013). The mechanism underlying slowing could be operating at an early stage of visuospatial processing common to simple and complex stimuli and faces and objects, or perhaps arise from neural processing at later stages that is common to all classes of visuospatial stimuli. Thus, age-related visuospatial slowing appears to be both general and specific in nature; that is, the current findings are consistent with rates of age-related slowing in the visuospatial domain that are domain-specific, in that they tend to be greater than those observed in the verbal domain, but which remain general within the visuospatial domain, in that, contrary to expectation based on age-related changes in accuracy measures, object and face processing are both slowed to an equivalent degree.

The absence of an age-related dissociation between face and object processing speed in the current study is a compelling finding; however, establishing the truth of a null hypothesis is always challenging. In the present case, Bayesian analyses were used to supplement findings of differences that were not statistically significant, and these analyses provided strong evidence that given the current data, it is many times more likely that the null hypothesis is correct than that face processing and object processing are differentially affected by age-related changes. Although the current study was not designed to address the neural bases for age-related slowing, it seems plausible that a mechanism at an early stage of processing, en route to face-specific processing regions, could account for slowing in both face and object processing. More research obviously will be needed to define the underlying neural mechanisms responsible for age-related visuospatial slowing. However, the existence of separate brain areas specialized for lower level visual processing as well as other areas specialized for higher level processing of specific classes of visuospatial stimuli (e.g., the fusiform face area and the parahippocampal place area) hopefully will expedite this exciting investigatory process.

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Appendix

Table A.1 Mean (*M*) Accuracy Rates (in percentage) and Standard Deviations (*SD*) for the Face and Object Task Batteries as a function of the YA Groups

	TASKS						
	TASK 1	TASK 2	TASK 3	TASK 4	TASK 6	TASK 7	TASK 8
GROUP	FACE BATTERY						
WU (*M*)	85.4	84.9	94.5	88.5	92.5	84.8	87.5
WU (*SD*)	7.8	7.9	5.9	8.6	6.3	7	7.7
MTurk (*M*)	83.8	85.5	92.9	88.1	90.7	83.2	87.5
MTurk (*SD*)	7.6	7.1	5.8	8.7	6.8	6.7	5.6
	OBJECT BATTERY						
WU (*M*)	91.2	92.6	97.6	94.8	95	93	85.4
WU (*SD*)	5.6	5.3	5.5	4.8	4	3.7	7.3
MTurk (*M*)	92.4	95.9	96.6	95.8	94.9	92.7	88.6
MTurk (*SD*)	6.2	4.3	5.1	5.1	3.7	3.8	6.6

Note: WU = Washington University Undergraduates, MTurk = Amazon Mturk Adults

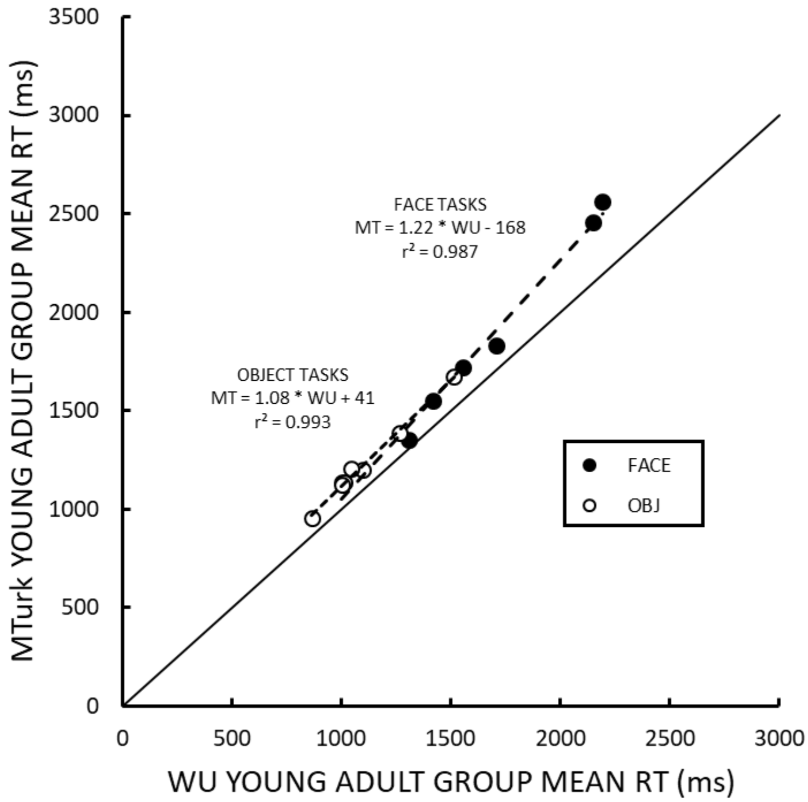

Figure A.1. RTs on face and object processing tasks (filled and open circles, respectively) for younger adults recruited from MTurk as a function of the corresponding RTs for younger adults recruited from Washington University (WU). If the corresponding RTs of the two groups were equal, the data points would fall on the diagonal line. Although two separate linear regressions were fit and shown here for each stimulus domain, analysis revealed that these data were best fit with a single linear function using tests analogous to those used to analyze the age group analysis shown in Figure 5.2. Importantly, the MTurk group differed from the WU group in purely quantitative terms (i.e., the MTurk group was about 20% slower than the WU group), rather than showing any evidence of a qualitative (e.g., stimulus domain) difference.